Modification of Aircraft to Serve as Humanitarian Mobile Medical Facilities: A Systems Engineering Approach

Undergraduate Thesis for Honors with Distinction Graduation

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Abstract

What does it take to change the world? In a world strife with poverty, disease, disaster, and death, this thesis attempts to shine a light of hope on the seemingly hopeless by engaging these problems directly, in an unconventional way. The primary objective of this effort is to detail the engineering modification of existing aircraft to serve as mobile medical facilities in humanitarian operations, in order to serve highly impoverished and remote regions of the world lacking reliable infrastructures (notably runways) and healthcare systems, especially in times of crisis and disaster. It is believed that an aircraft equipped with onboard medical facilities could be further modified to exhibit short takeoff and landing (STOL) capability as well as effectiveness in landing on rugged terrain. A variety of existing, proven technologies will be studied and integrated with a suitable existing aircraft, the C-130 Hercules transport, in order to determine their effectiveness in enhancing mission performance capabilities, while avoiding extensive alterations to the exterior body and structure of the airframes. These modifications mainly include wing leading edge extensions, double-slotted flaps, spoilers, and auxiliary small turbofan engines, which are projected to increase aerodynamic lifting capability ($C_{L,max}$) by up to 95% and increase takeoff thrust by 40%, leading to a reduction of dirt field takeoff ground distance from 3500 ft to 1500 ft – 2200 ft or less and a reduction of landing ground distance from 1700 ft to 1000 ft or less. Deeper aerodynamics analysis has served to verify the above claim, and detailed fluid-structural analysis (to give further confidence in the results) is currently underway. Furthermore, modularization of the onboard hospital itself is being explored, such that the aircraft and the hospital can be decoupled for mission flexibility, in order to both make use of the *same* aircraft as a rescue/transportation platform and to use the offloaded Mobile Hospital as a field clinic. Thus, this systematic approach to aerospace design engineering will strive to assure an innovative solution that is viable in the present day, making it implementable in a very short amount of time. Furthermore, the solution will be developed in such a manner that systems integration challenges, system complexity, and cost/maintenance required are minimized, so that humanitarian operations are expanded without overburdening the organizations that fund and support them. Hence, this flying hospital should lead to a wider outreach and subsequent servicing of a much larger and – as of yet – difficult to reach population.

A Note From The Author

The intent of this thesis is to embark on a journey to change the world. The author believes that bringing life-saving aid to people facing immediate need today will help to ensure for them a better tomorrow. He aspires to bring the idea discussed herein to life, and he fully intends to implement it as part of this life-saving and life-changing process in the form of his own humanitarian organization and through partnerships with others.

However, the author knows that he will need help: Hence, the underlying motivation for writing this thesis is both to inspire others and to gather support for this undertaking. Thus, much of this thesis has been written to be general audience-friendly (while still preserving the technical details of the engineering analysis), so that the author's message is not lost in a cloud of technical jargon. The in-depth technical backbone of this effort is left to particular sections of this thesis and will be denoted as such. In this way, readers can direct their attention to the message and the mission, and not to the mathematics, if they so wish. Thus, the author hopes that this effort will help to forge alliances with any interested in this philanthropic quest, alliances that will hopefully last well into the future.

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Introduction

“What if we could put a hospital inside an airplane and fly it to a place in need?” This is the question that the author asked himself five years ago….

Today, as it stands, we are surrounded by a myriad of complicated situations: Whether it is the peril of disaster, the curse of disease and famine, or the fear of economic downturn, our problems unite us all in that we all have something to lose. Some of us have more to lose than others. For example, the World Health Organization estimates that 863,000 malaria deaths occurred in 2008, with 767,000 alone occurring in Africa. Furthermore, 243 million malaria cases occurred worldwide that year, and as of now, half of the global population is at risk of contracting malaria. (1) And this is just one disease.

Millions die worldwide *each year* from vaccine preventable diseases (VPDs). In 2002, an estimated 2,550,000 children under the age of 5 died from VPDs, the majority of whom were from the poorest regions of the world (Africa, Southeast Asia, Eastern Mediterranean, Western Pacific). (2) Another 17,708,000 infants worldwide were never reached. Yet, it is well within our reach to prevent such needless death.

Furthermore, many people worldwide lack access to suitable clinics. Many ailments can be prevented through simple means, but others require greater attention and care. Critical care and hospitalization are not an option for many, especially in times of disaster. Take for example the recent earthquake in Haiti. Haiti is said to be the poorest country in the Western Hemisphere, and lacked proper medical facilities even before the earthquake struck. Afterwards, what medical facilities it had were destroyed, leaving Haitians without hospitals of their own.

What are we to do? Do we stand by and watch these horrors as they unfold, or do we do something about them? Enter the Mobile Hospital: This is literally a hospital integrated with some type of vehicle (in this case, an aircraft), a traveling healthcare system, so to speak. While this is not a substitute to a solid infrastructure, it may serve to supplement it at the very least. However, where the hope of no such infrastructure exists, it may serve to provide one by landing almost anywhere and treating almost anyone.

After commencing the present project, it was discovered that several examples of mobile hospitals *already* exist today and have seen many operations worldwide, mainly in the impoverished regions discussed above. These flying hospitals are older fleet aircraft whose interiors have been converted to be fully-equipped surgical facilities, each complete with an operating theatre, recovery rooms, and other associated stations and equipment. These aircraft are operated by the humanitarian charity organizations ORBIS International and Mercy Airlift International. Since their inceptions, these organizations have treated millions of people through both onboard hospitalization and other forms of care, including temporary field clinics and local hospitals. Mercy Airlift, which was established in 1968, is able to treat on the order of 8000 people during a typical deployment, which lasts 21 days. Its Flying Hospital alone is able to handle 30 patients per day. This group conducts five such deployments per year, especially in disaster situations. (3) ORBIS International follows a slightly different model, in that it focuses on eye surgeries and general optical care, and because its Flying Eye Hospital serves as a surgical teaching hospital, allowing

ORBIS to spread knowledge and training to local doctors in these regions. ORBIS has directly treated over 9.7 million people since its founding in 1982. (4)

This thesis is part of an effort called The MedWing Mobile Hospital Project, an effort catalyzed by the author and his project partner, Alvaro Hernandez, at the Ohio State University College of Engineering. The primary objective of this effort is to develop aircraft capable of serving as mobile medical facilities during humanitarian operations, in order to serve highly impoverished and remote regions of the world lacking reliable infrastructures and healthcare systems, especially in times of crisis and disaster. A particular emphasis will be placed on short takeoff and landing (STOL) capability as well as effectiveness in landing on rugged, rough, unprepared terrain, allowing for greater flexibility in mission operations. This solution can be approached in two different ways: One is design, the other is modification.

This thesis will center upon the modification of an existing aircraft to achieve the mobile hospital mission (while the thesis of Mr. Hernandez will focus on the design of such an aircraft). The baseline aircraft for the present investigation is the C-130/L-100 Hercules transport, which was chosen for the following reasons: It already exhibits considerable rugged terrain and short takeoff and landing performance, it is reputed for its great utility to operators in developing parts of the world, and 114 commercial units have been produced and sold between 1965 and 1996 (5). This implies that the aircraft is easily available to humanitarians around the world (and it has already seen many operations involving humanitarian aid delivery, medical evacuation, and general rescue). The C-130 is pictured in Figure 1 below:

Figure 1: C-130 Landing

This modification process involves retrofitting the C-130 aircraft with new aerodynamic controls and surfaces, as well as auxiliary small turbofan engines, in order to reduce takeoff and landing ground distances — thereby enhancing takeoff and landing performance — while still avoiding extensive alterations to the exterior body and structure of the airframe. This would make the MedWing C-130 even more suitable for operations in remote regions of the world lacking both hospital and runway infrastructures. Furthermore, these after-market modifications have been selected such that cost, maintenance involved, and system complexity are minimized: Thus, the solution under consideration has been designed such that philanthropic organizations and benefactors can realistically obtain the aircraft without great hassle and cost, and that the proposed modifications to this aircraft can be realistically applied and tested. Hence, the solution should be implementable in a very short amount of time.

The body of the present thesis will consist of several chapters. The first chapter is a discussion of some of the healthcare and disaster relief challenges that the world is faced with today, in order to highlight these problems in greater depth and detail. The second chapter involves the search for a solution to these problems and highlights what the requirements must be for a mobile hospital to function successfully during humanitarian missions. The third chapter details the qualitative definition of a potential solution to these problems, in order to give a general overview of the concept.

The fourth chapter marks the beginning of the quantitative technical investigation of the performance modification effects, consisting of a preliminary evaluation of the concept (Phase I of the modification process). The fifth chapter, which is Phase II of the modification process, will involve a more detailed investigation of systems integration and performance for the solution proposed in Phase I, using advanced engineering analysis and simulation software. The results from these analyses will be used to make a second, refined assessment of the performance evaluated in Phase I.

In the sixth chapter, the interior of the aircraft will be described, consisting of a high-level overview of the mobile hospital. Most importantly, it should be noted here that the mobile hospital is itself modularized (as it will be housed in a containerized fashion inside the C-130 cargo hold) and therefore can be decoupled from the aircraft in order to achieve aircraft-hospital independence. Thus, the aircraft can become a multi-use platform, leading to expanded rescue, transportation, and resupply capability during humanitarian missions. This also implies that the hospital modules can be left behind at particular locations in order to serve as start-up clinics for the local community.

Finally, conclusions will be drawn from the study at hand, and the next steps for Project MedWing will be discussed, so that the solutions proposed herein can actually be *implemented* during humanitarian missions in the very near future.

The Problem

Overview

It is said that we live in a "globalized" society: The phrase is everywhere. But what does that mean, exactly? One could argue that globalization means "people working together across borders to achieve a common goal." If this goal is economics, it seems to work well for those that stand to gain from trade. If this goal is data transfer and networking, then today's communications systems are highly effective in making that possible. But what if the goal were something else, something deeper, something more profound than the exchange of money and information? What if being globalized means *actually solving* the world's problems? Surely, we could collaborate across borders to achieve *this* common goal. And that would make us a *true* global society…

So what are the problems? The answer is that there are too many of them to be listed in this thesis, too many for anyone to list in any thesis, and *far* too many for anyone to tackle on their own. Take for example the gross national income (GNI) per capita of each continent, and compare that with the average life expectancy, as in Figure 2 below:

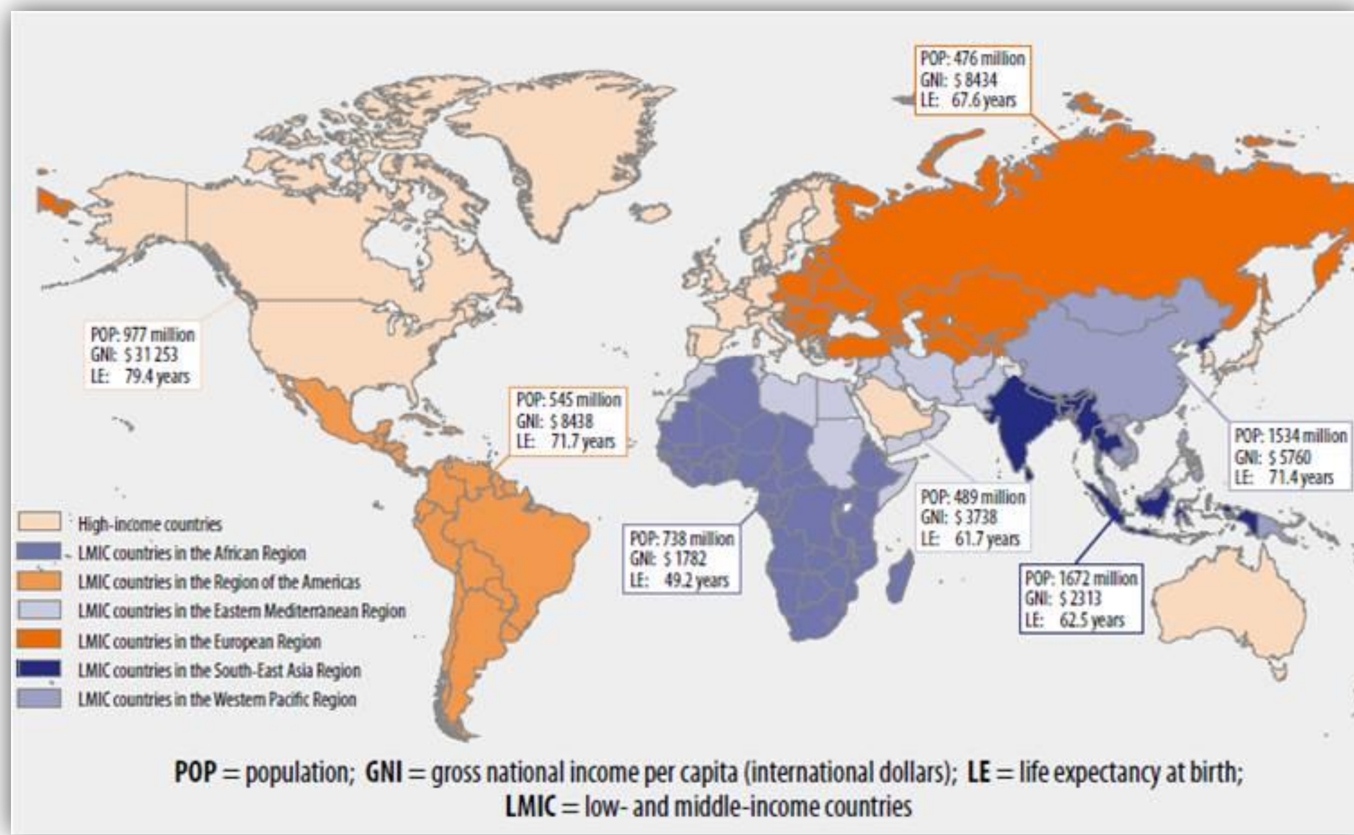


Figure 2: Low and Middle-Income Countries Grouped By WHO Region (1)

Of particular note are the following data, shown in Figure 3 below:

Figure 3: Half the Life Expectancy, Half a World Away

It is astounding to see that such disparity exists among people living on the *same planet*, and thus the *same global community*. What is also astonishing is that only 1 out of 3 Africans has access to medical care of any kind, and that *only* about 1 out of 3 Africans lives in an urban community (which are often the only places where any medical care exists at all), meaning that *two-thirds* of the African population lives in rural areas, which do not have access to healthcare of any kind. But for those of us living in the US, we really do not have to look far to see some of these problems at full play, as shown in Figure 4 below:

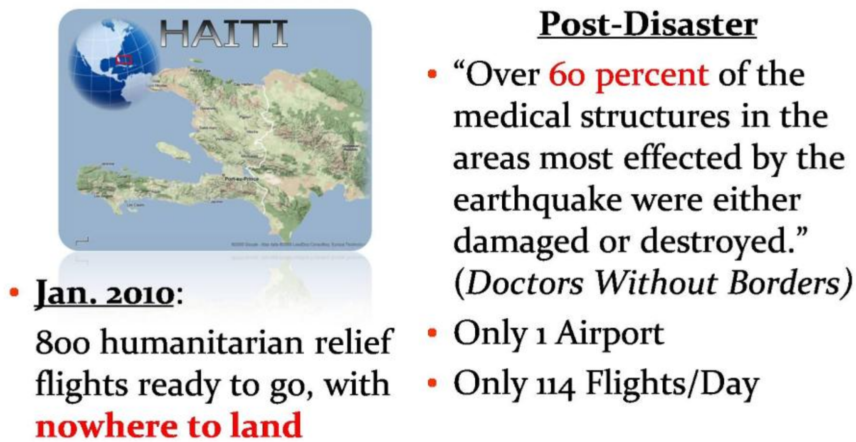


Figure 4: Haiti

Clearly, there was a problem of access during the Haitian earthquake of January 2010, since many aircraft bringing aid had nowhere to land. The same problem exists for other disaster-stricken regions of the world, whether their communities be urban or rural.

So what can we do? As members of this *global society*, we need to do something, right? Perhaps we could take the healthcare with us: This is the idea of the Flying Hospital, literally a hospital on an airplane that can land anywhere and treat anyone.

Why a FLYING HOSPITAL?

So, why are we proposing a Flying Hospital, and not (necessarily) proposing global infrastructure improvements (at least, not upfront)? First of all, the founding members of MedWing are in complete agreement that the establishment of more permanent clinics (in a manner that is acceptable and compatible with the local people and culture, of course) is imperative. Furthermore, hunger relief, education, and poverty alleviation in general are absolutely crucial for the survival and the success of our fellow neighbors, especially to achieve societal stability and sustainability. No one is denying this, and MedWing fully advocates these end-goals. However, something must be done in the meantime, until such a time as these end-goals are met and the world becomes a much happier place.

This, of course, is where the MedWing Flying Hospital comes in: The idea is to be able to help anyone, anywhere by utilizing the unparalleled responsiveness and capability of an airplane, coupled with the extraordinary abilities of humanitarian doctors, rescue workers, and other personnel, as well as the novel capabilities of the Mobile Hospital onboard. The drive behind implementing such a Flying Hospital is detailed below:

Why a *Flying Hospital*?

- **Highly mobile, Highly capable**
    - A Flying Hospital could provide *immediate* aid almost anywhere in the world, at a moment's notice: Why wait when it comes to saving lives?
    - The idea is applicable to disaster-relief situations or to ongoing crises around the world.

- **Convenient: Bring the Hospital to the People**

    - We could cut down ambulatory trips and costs during a given humanitarian mission: Rather than taking people to the hospital, we could bring it to them, resulting in less careflights and other emergency medical transportation of people to better-equipped hospitals (as was the case in Haiti recently).

    - The necessary tools are at the doctor's fingertips: Doctors can now perform their duties in a safer, more efficient, and more effective manner, enabling them to heal patients with less worry and less scrambling for supplies than before.

    - The mission team could now avoid extensive customs protocol at local airports, where supplies and equipment are often stolen. This means a greater abundance of the supplies needed for a given mission should exist.

- **Sustainability**

    - The ultimate goal is to leave something behind, to sow the seeds of *change* for a given community: We can never leave those that we help worse off than they were before – we have to make a lasting difference, so that the end-goals mentioned above are ultimately met and so that someday, perhaps, Flying Hospitals are no longer needed. We will revisit this idea throughout this thesis.

We could summarize the above in just three words: **Access**, **Capability**, and, of course, **Sustainability**.

Current Solutions

As the creators of MedWing discovered shortly after embarking on this journey, there are several organizations operating flying hospitals already! This was encouraging for the author and Mr. Hernandez, because not only had others thought of the same idea, they had found a way to make it viable, financially feasible, and most of all, effective. These commendable humanitarians are described below:

ORBIS International

ORBIS International is a nonprofit organization founded in 1982, whose primary focus is the treatment of vision-related illnesses such as cataracts, a common but easily treatable problem in the poorer parts of the world. Since its inception, ORBIS has carried out more than 100 programs in 86 countries, while directly treating millions of people. Furthermore, ORBIS's most recently acquired DC-10 aircraft will serve as their third Flying Eye Hospital when it enters service soon. Intriguingly, this aircraft amounts to a $2-3 million charitable donation from FedEx, which is one of ORBIS's partners. This is far cheaper than the normal $40-60 million that a new aircraft of that size would cost. In fact, ORBIS's entire operation fits within the scope of $60 million, based on its highly-diversified yearly revenue stream. Even more interestingly, it should be noted that the Flying Eye Hospital Program cost amounts to about 1/6th or less ($6-10 million) of the annual revenue stream (6), making ORBIS a living example of the feasibility of such a venture. The Flying Eye Hospital is featured in Figure 5 below:

Figure 5: ORBIS International's Flying Eye Hospital

Unfortunately, the DC-10 aircraft requires on the order of 8000 ft of paved runway to take off, making it difficult for ORBIS to reach locations where most of the runways are short, dirt strips, and making it impossible for them to reach locations with no runways at all. This key fact will play an important role during the remainder of this thesis.

Mercy Airlift International

Mercy Airlift International is a similar nonprofit organization founded in 1968, whose primary focus is the treatment of post-disaster victims and response to health and hunger crises. The operating theater housed aboard Mercy's L-1011 aircraft is particularly effective in after-disaster situations, where surgical care is a must. The remarkable thing about Mercy is its extraordinary mission capabilities. To highlight, Mercy's teams are able to treat 8000 patients per 21-day mission, with potentially 30 patients per day being served by the Flying Hospital itself (pictured in Figure 6 below). (3) Unfortunately, Mercy is also unable to reach populations that are cut off from large, paved runways, making remote location access difficult once again – in a disaster situation similar to Haiti's, it would be difficult for Mercy to reach airports that are inoperative or nonexistent.

Figure 6: *The Flying Hospital*, Mercy Airlift

So, what can be done by MedWing — which is now so inspired to move forward with its humanitarian mission — to reach the unreachable and to treat the otherwise untreatable? The answer lies in Short Takeoff and Landing capability, better known as "STOL."

The Search for a Solution:

Minimizing Takeoff Roll, Maximizing Access

Overview

Based on the nature of the problem and on the current set of solutions available, a new solution is proposed by the MedWing Project: An existing aircraft must be modified such that both hospital capability and regional accessibility are maximized (while keeping in mind the potential tradeoffs between hospital capability and access). Furthermore, as per the general requirements set by the MedWing Project, an aircraft must attempt to meet or exceed the following requirements (shown in Table 1 and Table 2 below), in order to exhibit similar medical capabilities as the aircraft of ORBIS and Mercy Airlift, while also demonstrating enhanced remote location accessibility:

Table 1: MedWing General Aircraft Requirements

Requirements (Aircraft)	Required Values	Desired Values	*NOTES*
Flight Crew	2	2	*Based on 200-lb crewmember*
Passengers	25	40	*Based on 280-lb passenger (includes luggage/supplies) -- These are mostly doctors and other staff*
Cabin Height	7 ft		
Cabin Width			
Hospital Aisle Width	3.25 ft	4 ft	*Based on ORBIS Data/ Stretcher width*
Cargo	66000 lbs	72000 lbs	*Based on ORBIS Data/ Mercy Airlift Data*
Maximum Takeoff Distance	4500 ft	3000 ft (or less)	
Maximum Landing Distance	4500 ft	3000 ft (or less)	
Cruise Mach Number	0.5	0.8	
Range	3000 nmi	3500 nmi	

Table 2: MedWing General Hospital Requirements (Based on ORBIS Layout) (7)

Requirements (Hospital)	Required Values	Desired Values
Operating Room Relative Length	15 ft	18.25 ft
Operating Room Relative Width	10 ft	15 ft
Operating Room Area	(none)	250 ft^2
Substerile Area	(none)	150 ft2
Recovery Area	(none)	200 ft2

It should be noted that meeting these requirements is a high-level goal, one that every solution designed under the MedWing Project will strive to accomplish: However, it must be stated that meeting *all* of the above requirements using an existing aircraft will be difficult: Most aircraft available to humanitarians today are either capable of lifting large loads or capable of takeoff and landing from short fields and runways, but not both. Thus, the starting point in reconciling these seemingly opposite issues would be to find a middle ground – in other words, a "best of both worlds" aircraft, one that is already-well suited to the MedWing mission. Luckily, such an aircraft exists already and is in widespread use today by military, civilian, and especially, humanitarian operators worldwide: Enter the C-130 Hercules airlifter.

Case Study: C-130 Transport Aircraft

The C-130 medium transport is a well-reputed airlifter, a true jack-of-all-trades aircraft. Since the deployment of the first C-130 Model A aircraft in 1956, the design has seen many advancements, with the newest design (Model J) still in production today. This airplane has proven itself as a flexible, versatile platform, one that can be easily reconfigured for passenger or cargo duty. In fact, the Hercules has served in a variety of operations since its introduction, including cargo and personnel airlift, aeromedical evacuation, weather and other scientific observation, Antarctic resupply, aerial firefighting, and humanitarian missions (such as disaster relief). Much of the mission-specific equipment can be added or removed very easily, allowing the C-130 to revert to its cargo-carrying role in a very short time. (8)

Furthermore, the C-130 is capable of short takeoff and landing from rough, unimproved dirt landing fields as short as 3000-3500 ft (depending on the type of C-130). (9) This makes the aircraft already well-suited for humanitarian missions in many parts of the world, where unprepared fields (which are reasonably straight and level dirt fields or roads (10)), can be found, whether natural or man-made. Such a dirt strip landing is shown in Figure 7 below:

Figure 7: C-130 Dirt Strip Landing

Thus, such versatile performance has made the C-130 the most popular cargo aircraft in the world, with more than 2200 units sold to more than 60 countries worldwide by manufacturer Lockheed-Martin Company. (11) In fact, due to the utility of this aircraft, Lockheed sold 114 commercialized units (dubbed the "L-100 series") between 1965 and 1996, many of which are in use in developing parts of the world. (5) Moreover, there were over 1500 units operating in 72 countries as of 2009 (12). This could mean that a commercial or demilitarized version of the Hercules could be obtained by a humanitarian organization in the same way that ORBIS and Mercy Airlift have obtained their respective aircraft.

Moreover, this aircraft is in fact large enough to accommodate many of the surgical and other equipment required by mobile healthcare. To expound: The basic, non-stretched C-130 airframe is almost 98 ft long and can carry around 40,000 lb of payload. The payload (whether it consists of supplies, equipment, people, or some combination thereof) can be easily loaded and unloaded via the hydraulically-powered rear loading ramp. The cabin, which on non-stretched models is about 40 ft in length and 10 ft in width, has already been designed to take on modularized cargo, making internal configuration changes very efficient. The L-100-20 and L-100-30 stretched civilian versions boast even larger internal cabins. (13) Examples of the C-130 cargo loading and cabin are shown in Figure 8 below:

Figure 8: Examples of C-130 Cargo Ramp and Loading

Considering all of these factors, the C-130 Hercules is an excellent candidate for humanitarian operations all over the world, especially in remote regions. But can the performance be improved even more, in order to gain greater access, while still preserving its heavy-lifting abilities? The present thesis will attempt to answer this question.

A Note on Takeoff Distance: How Short is **Short***?*

The term short takeoff and landing (STOL) has appeared many times throughout this thesis, but one might be wondering, What is meant by *short*? To answer this question, we must first take a brief look at some of the physical aspects of flight:

For any aircraft in flight, there are always four main forces acting on it: Weight, exerted by the pull of Earth's gravity on the mass of the aircraft; Lift, the aerodynamic force generated mainly by the wings of the aircraft to counteract the weight, allowing the aircraft to stay airborne; Drag, which is the result of air molecules colliding with and rubbing against the body of the aircraft as it travels through the air; and Thrust, which is used to counteract drag in order to propel the aircraft through the air. These four forces are depicted in Figure 9 below:

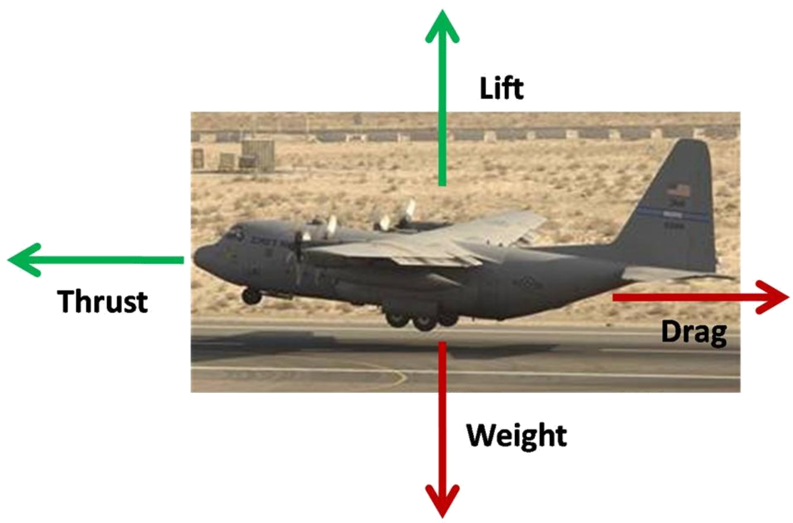


Figure 9: Four Forces Acting on an Aircraft

In cruising flight, when the aircraft has climbed to its target altitude, these four forces are in equilibrium (that is to say, the lift is equal to the weight and the thrust is equal to the drag). Thus, the aircraft can keep cruising at a steady speed when this is the case. However, during the takeoff phase of the flight, when the aircraft is initially at rest, lift must be generated to overcome the weight of the aircraft in order to get it aloft.

For conventional, fixed-wing aircraft (such as the C-130), this is done by accelerating the aircraft down a runway (or an open dirt field during remote operations), such that more and more air flows over the wings, thereby generating an increasing amount of lift. When the aircraft reaches its takeoff speed (called V_{TO}), it has generated enough lift to become aloft on its own; this occurs at the end of the aircraft's "ground roll," or the distance covered by the aircraft on the ground as it accelerates to takeoff speed. For the non-stretched versions of the C-130, this distance is roughly 3000-3500 ft for a maximum takeoff weight (MTOW) of 155,000 lbs (which is the standard MTOW for the majority of current-day C-130 aircraft, civilian or military, stretched or non-stretched), as mentioned above.

Landing distances are generally shorter for most aircraft, as the aircraft are generally lighter when it is time for landing (as much of the fuel has been expended, leading to a reduction in weight). This means that the aircraft can generally be stopped in less distance on the ground (the landing roll for a standard C-130H is around 1700 ft, based on a landing weight of 130,000 lbs). (13)

Returning to the above question, it can be said that the C-130 reaches takeoff speed in a much shorter distance than other aircraft of similar weight and size. For example, the current commercial fleet's Boeing 737 aircraft has a takeoff roll of about 8000 ft (14), which is more than 1.5 miles in length. However, a standard C-130 requires only 38-44 % of the ground distance covered by the Boeing 737 during takeoff. To put this into perspective, the C-130 requires a takeoff distance equal to the length of about 4 standard Manhattan city blocks (which are around 900 ft in length each). On the other hand, the 737 travels almost 9 city blocks before takeoff! Moreover, it is the aim of this thesis to reduce the C-130 takeoff ground roll to around 1500 to 2200 ft (or less) through modifications. This equates to a takeoff distance of about 1.5 to 2.5 Manhattan city blocks.

Performance Modifications to Accomplish the Mission

Overview

Can the capabilities of the C-130 be improved further, while still maintaining cost-efficiency and minimal complexity? And if so, what should be improved, exactly? Recalling Figure 9, it can be seen that that the dynamic behavior of a given aircraft depends on the forces acting on it. Naturally, when designing an aircraft, an aerospace engineer strives to maximize lift and thrust while minimizing weight (due especially to the structural skeleton of the airframe and the fuel needed to propel the aircraft) and drag (due to the size, shape, and flight velocity of the aircraft). However, the thesis at hand is not concerned with designing a *new* aircraft (this has been left to Mr. Hernandez): Rather, here we are modifying an *existing* aircraft, which presents a whole new set of challenges – these will become clearer throughout the rest of this thesis.

As a consequence, drag and weight reduction is somewhat beyond the scope of this thesis. In regard to drag, drag reduction (for the whole airframe, at least) requires that the shape and material roughness properties of the airframe be changed in a drastic manner – this can be very extensive and very expensive. In regard to weight, it was decided that the gross takeoff weight of the aircraft would remain at 155,000 lbs, in order to fully utilize the 38,000 to 52,000-lb payload capacity afforded by the C-130 models. (13)

This leaves the author with the option of augmenting the lift and thrust of the aircraft in order to better its takeoff and landing performance, which can lead to reduced takeoff and landing distance. This is conceptualized in Figure 10 below:

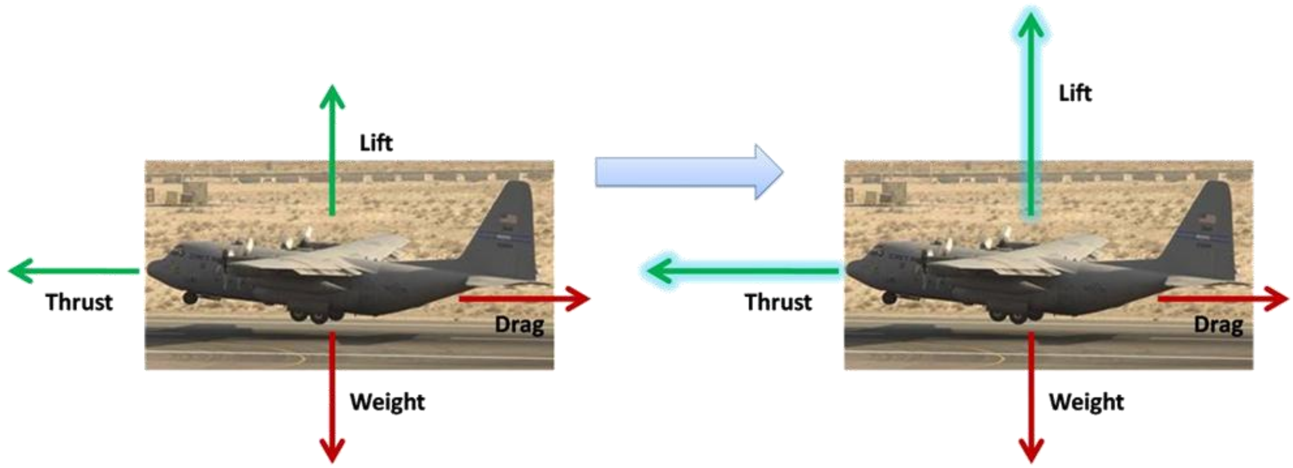


Figure 10: Before and After Comparison of Lift and Thrust Augmentation

Furthermore, thrust modifications are fairly straightforward to understand: Thrust, after all, is produced by the aircraft's engines, which are a self-contained system. Thus, adding more thrust involves either upgrading the existing engines or adding new ones (or both, if possible), rather than making any changes to the airframe itself. However, lift modifications are a bit more complicated to grasp. Thus, we must first explore what lift is and how it is generated:

Fundamentally, lift is nothing but the force that results from a difference in pressure created by an object (in this case, a wing) in fluid flow. A low pressure region is created over the upper surface of an aircraft wing, as the faster moving flow over the upper surface has "expanded" such that the air molecules traveling over the wing exert less pressure than those traveling below the wing, which are slower and exert higher pressure. This difference in pressure leads to the generation of a lifting force. This phenomenon is illustrated in Figure 11 below:

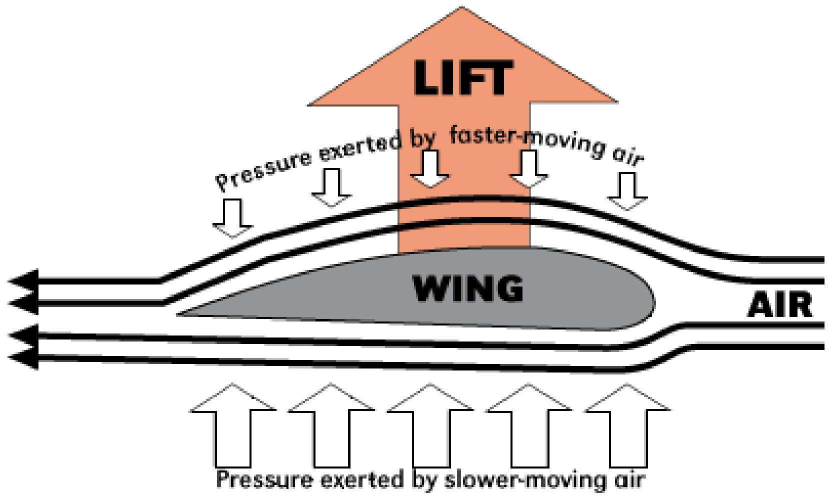


Figure 11: An Illustrated Synopsis of Lift

In order to maximize the amount of lift force generated by the wing, several aspects of the wing can be modified:

1) The camber (curvature) of the wing can be increased, such that the flow over the top surface expands more, resulting in even less upper surface pressure and larger net pressure (and force).
2) The surface area of the wing can be increased such that the net upward pressure exerted by the flow acts on a larger surface.
3) The energy of the flow over the upper surface can be increased such that the difference between upper and lower surface pressures is further augmented, resulting once again in a larger net pressure (and force).

It should be noted that this is exactly what happens in flight (specifically during takeoff and landing) to an aircraft wing: In order to actively change the wing's geometry, control surfaces are deployed to literally "morph" the wing into a more capable lifting shape, often achieving all three of the geometric changes highlighted above.

Furthermore, the lift force acting on an aircraft is described by the following equation:

$$L = \frac{1}{2}\rho V^2 S C_L \,,$$

where ρ is the density of the oncoming air, V is the velocity of the oncoming air, S is the top-view area of the wing (reference area), and C_L is the lift coefficient, which is a nondimensionalized parameter that describes the lifting ability of a given wing based on its geometry and angle with respect to the oncoming flow (called angle of attack). Based on this equation, it can be seen that, all other things being constant, wing aerodynamic geometry (C_L) plays a great influence on aircraft lift. Thus, maximizing C_L leads to greater lift.

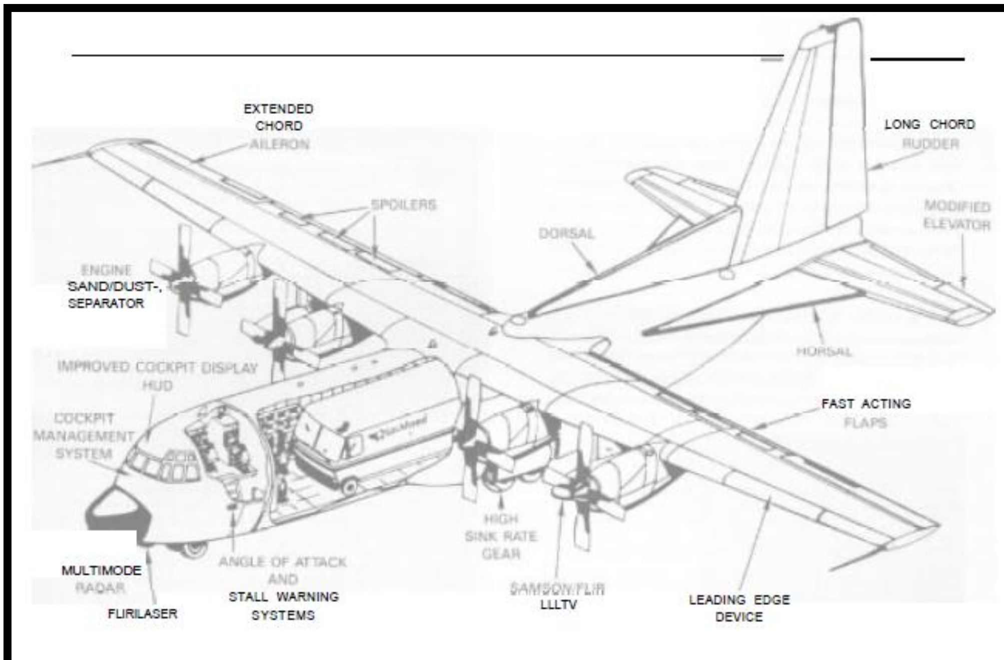
Furthermore, one can see that lift = weight occurs at a particular speed (V_{TO}), as dictated by takeoff lift coefficient ($C_{L,TO}$). Reaching this speed during takeoff requires sufficient thrust, as provided by the aircraft's engines. Thus, better thrust implies that this speed can be achieved in less distance, meaning shorter takeoff roll. Therefore, it is clear that the aerodynamics and thrust of the C-130 must be augmented in order to achieve greater performance. Thus, there are two sets of modifications that will be explored throughout the remainder of this thesis, as highlighted below:

1. **High-Lift Upgrades**: These consist of modifications to the C-130's wing high-lift system, consisting of updates to the wing surface and control systems. Fortunately, similar modifications have been researched previously as part of the Lockheed High-Technology Testbed (HTTB) program. These will serve as a basis/starting point for the aerodynamics study at hand.
2. **Propulsive Augmentation**: In order to increase takeoff thrust, small turbofan engines, which are normally used to propel business jets, will be integrated with the C-130 airframe using suitable structural locations on the wing. Similar extra engines have been used on military aircraft in the past, with deployable inlet doors to minimize drag during cruising flight.

Historical Background

Lockheed High-Technology Testbed: The STOL C-130

Of particular importance to the effort at hand is the Lockheed High-Technology Testbed (HTTB), which was a civilian C-130 (L-100-20) used by Lockheed to perform STOL research from 1984 to 1993 (13). This aircraft featured a variety of progressive modifications, which are shown in Figure 12 below:



Many of the HTTB's structural modifications are designed to enhance STOL performance.

Figure 12: HTTB STOL Modifications

In 1985, this aircraft set a runway takeoff length record of 1400 ft at 98,600 lbs takeoff weight, as well climbing records. (13). The main contributor to this success is the aircraft's high lift system, which consists primarily of wing leading edge extensions, double-slotted flaps, spoilers, and a host of other controls and extensions for better handling, as shown above. It is not clear at this point if all of the high lift modifications were completed by the 1985 test: However, based on the available flight test data (above) and the potential 95 % increase in lift due to external modifications, as indicated by Lockheed wind tunnel testing, the author has estimated that the HTTB high lift system will lead to a takeoff ground run of 1800 – 2700 ft for a C-130H (the current standard configuration) and 2200 – 3300 ft for stretched versions (which normally exhibit takeoff ground runs of around 4300 ft). This amounts to a 23 – 48 % reduction in takeoff ground distance. Thus, the HTTB test program proved that larger, heavier transports can take off and land in very short distances via fairly simple and cost-effective modifications. A detailed overview of the HTTB high-lift systems as applied to potential MedWing C-130 aircraft and a full report on takeoff performance estimation for all of the above C-130 configurations is given in the chapter entitled "MedWing Modifications, Phase I: Preliminary Aircraft/Technology Evaluation."

Jet-Assisted Takeoff: Then and Now

The idea of extra takeoff boost is not a new one. A prime example of Jet-Assisted Takeoff (JATO) is the Fat Albert aircraft, used by the US Navy's Blue Angels show team (pictured in Figure 13 below. This particular aircraft is a C-130 with eight 1000-lb thrust bottle rockets attached to either side of the aft fuselage. This airplane has demonstrated significantly reduced ground roll (on the order of 1500 ft, but at reduced MTOW). (15) This would help in meeting MedWing's takeoff requirement, except that the US military stopped using such rockets a number of years ago on their in-service C-130 aircraft, as the cost of usage became too high, indicating that the cost of using rockets during humanitarian missions would also be very high (keeping in mind that rocket fuel and bottles can be expensive when used frequently). Furthermore, rocket fuel (depending on the type) is a pollutant and can be detrimental to the health and well-being of the local population and environment that MedWing wishes to service. However, *replicating* this rocket performance is not out of MedWing's reach.

Figure 13: Fat Albert, JATO C-130

Instead of rockets, the use of auxiliary turbofan engines will be explored in the present thesis. These engines will each provide 5000-6000 lbs of additional thrust (for a total of 10,000-12,000 lbs of extra thrust) during takeoff and climb, such that takeoff speed is reached in reduced ground distance, and will remain inactive for the rest of the flight to minimize excessive fuel usage. Small doors will be deployed in-flight to close the engine inlets when said engines are not in use in order to minimize drag. Thus, when not in use, the extra engines should have similar drag properties as the external fuel pods which commonly hang underneath C-130 wings (this will be studied in greater detail at a later date).

Several suitable auxiliary engines for the MedWing Flying Hospital are the General Electric (GE) CFE 738 and the Pratt & Whitney PW306C (pictured in Figure 14 below), which meet the thrust requirement and are considered light and fuel-efficient, weighing only around 1300 lbs and exhibiting specific fuel consumption (sfc) of about 0.37 $lb_{fuel}/hr_{flight}/lb_{thrust}$. (16) It should be noted that auxiliary takeoff boost engines were featured on the C-123 Provider, an aircraft similar to the C-130 in use during the 1960s (as seen in Figure 15 below). This proves that such a concept is indeed useful given the proper selection of an engine.

Figure 14: Pratt & Whitney PW306C Auxiliary Engine

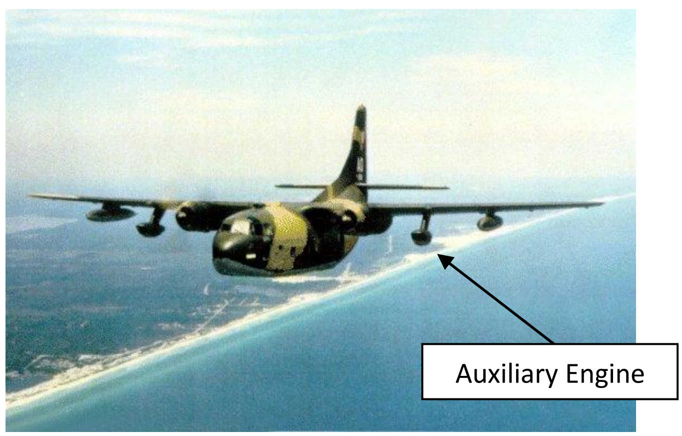


Figure 15: C-123 Aircraft, Featuring Auxiliary Takeoff Boost Engines

MedWing Modifications, Phase I: Preliminary Aircraft/Technology Evaluation

Overview

In view of the previous discussion, the aerodynamic and propulsive modifications of the MedWing C-130 are shown below and discussed in detail:

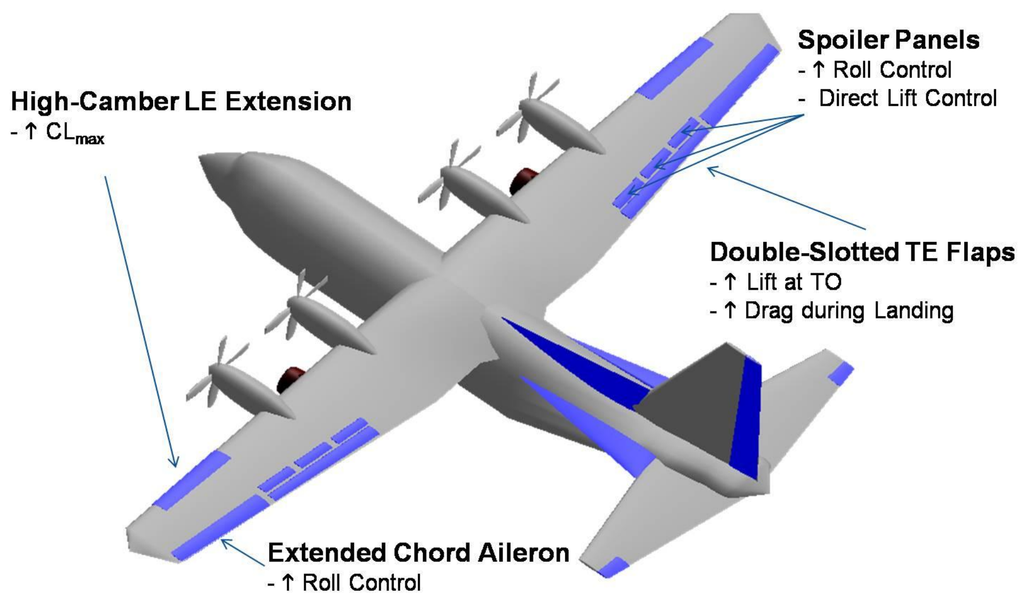


Figure 16: Wing Modifications

In Figure 16 above, the main wing modifications and their respective benefits are shown. To expand on the devices and the reasons for choosing them:

- **Drooped High-Camber Fixed-Wing Leading Edge Extensions**: Stated simply, these are curved extra structural pieces attached to the front end of the main wing, many times as after-market modifications. (17) The purpose of said extensions is to increase the camber (curvature) of the airfoils (local wing sections) of the modified regions such that the air flow over these sections is further expanded, leading to a larger pressure differential and thus greater lift. Moreover, these leading edge "cuffs" have proven to be effective at high angles of attack, since the flow remains better attached to the wing surface, thereby reducing stall speed and allowing for reduced approach speeds and landing rolls. (17) This phenomenon is shown in Figure 17 below:

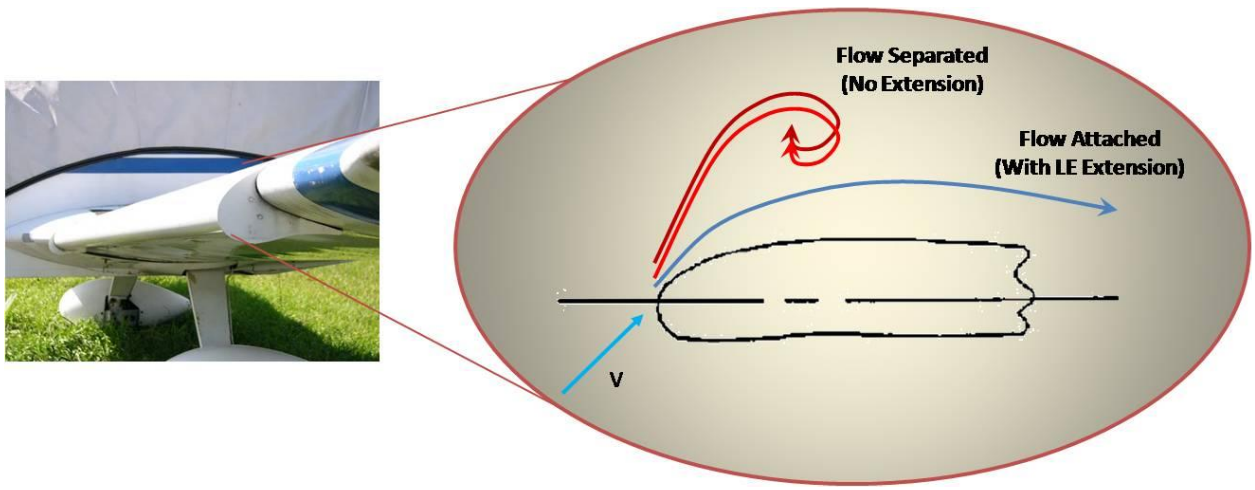


Figure 17: Leading Edge Extension

- **Double-Slotted Fast-Acting Trailing Edge Flaps**: These flaps are substituted for the Lockheed-Fowler flaps of the original C-130. Trailing edge flaps in general have proven quite effective in combination with leading edge slats and extensions (18), and double-slotted flaps in particular historically increase lift coefficient by a larger amount than do single-slotted or Fowler flaps. (19) Not only do these flaps increase wing area and camber, but they also provide two slots that act as nozzles, which accelerate/ energize the flow travelling through them in order to create faster-moving flow over the upper surfaces of the wing, lending to an increase in lift, especially in low-speed (near-stall) conditions. This is tremendously beneficial to a STOL aircraft, which operates at lower-than-average speeds. This performance benefit is highlighted in Figure 18 below:

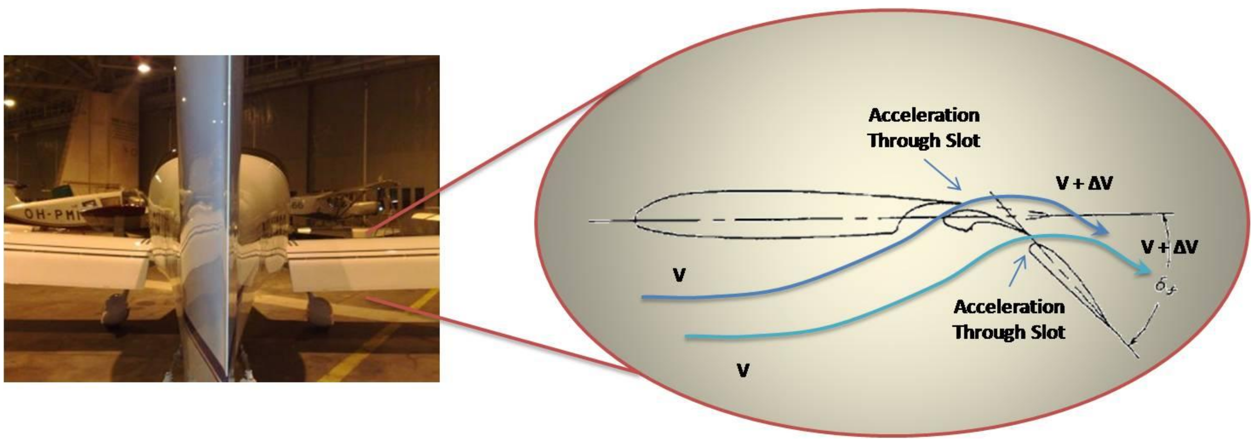


Figure 18: Double-Slotted Flap

- **Spoilers**: These panels deploy in order to literally "spoil" the lift on the wing (causing a rapid decrease in lift) and increase drag, enabling the aircraft to quickly slow down during the landing ground roll, thereby reducing landing ground distance. Spoilers can also be used to directly control lift during other phases of the flight and can thus be a good safety feature in the event that lift is larger than desired. This could be useful, for example, during the taxi phase on the ground, where lifting of the aircraft is not desired, or in the event of a sudden gust load on the aircraft, which can potentially increase lift and angle of attack such that the aircraft wing stalls or becomes overloaded, resulting in structural failure. Lastly, they can be effective in controlling the rolling motion of the aircraft. To see a spoiler in action, refer to Figure 19 below:

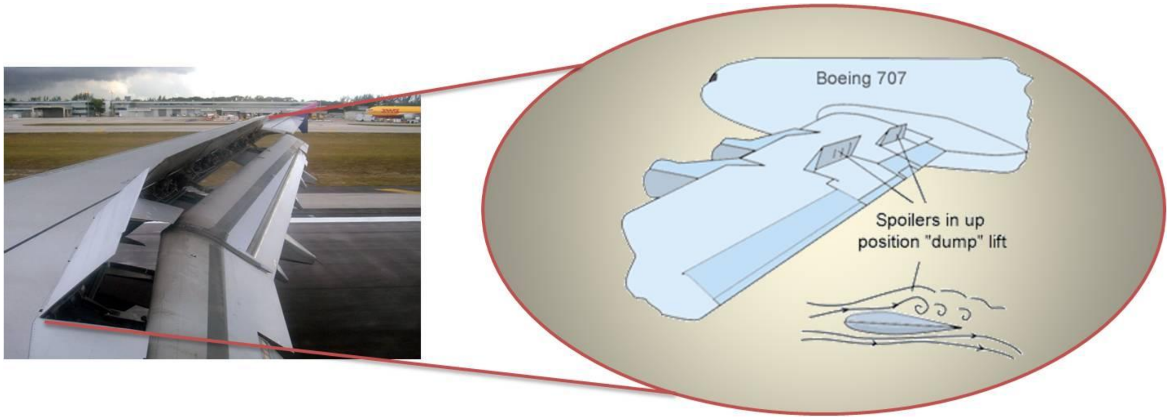


Figure 19: Spoilers (20)

- **Extended-Chord Aileron**: The existing aileron can be replaced with a longer one in order to provide greater control force during rolling maneuvers.

In Figure 20 below, modifications to the tail section are shown:

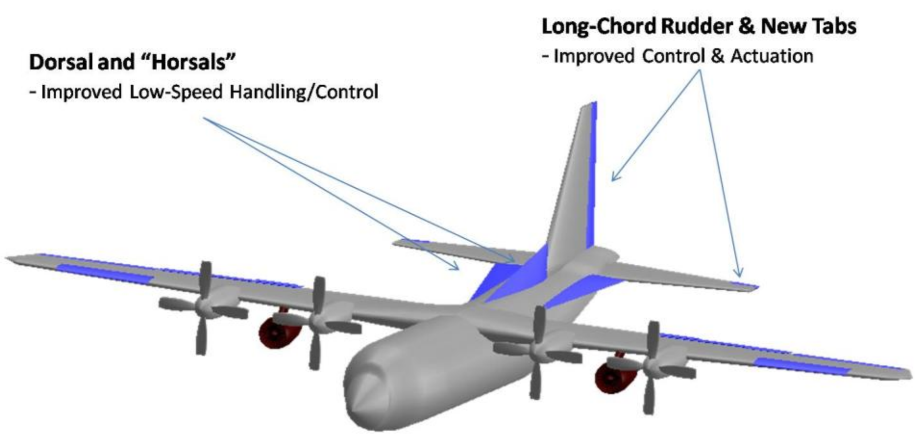


Figure 20: Tail Modifications

- **Dorsals and Horizontal Dorsals ("Horsals")**: These are basically 5-ft extensions of the vertical and horizontal stabilizer root chords, which provide additional improvements in low-speed handling and control, which, as stated previously, is important for STOL aircraft during takeoff as well as approach, descent, and landing. (21)
- **Long-Chord Rudder:** A larger rudder can replace the standard one in order to achieve greater directional control.

In Figure 21 and Figure 22 below, modifications to the landing gear as well as the addition of auxiliary propulsion are shown:

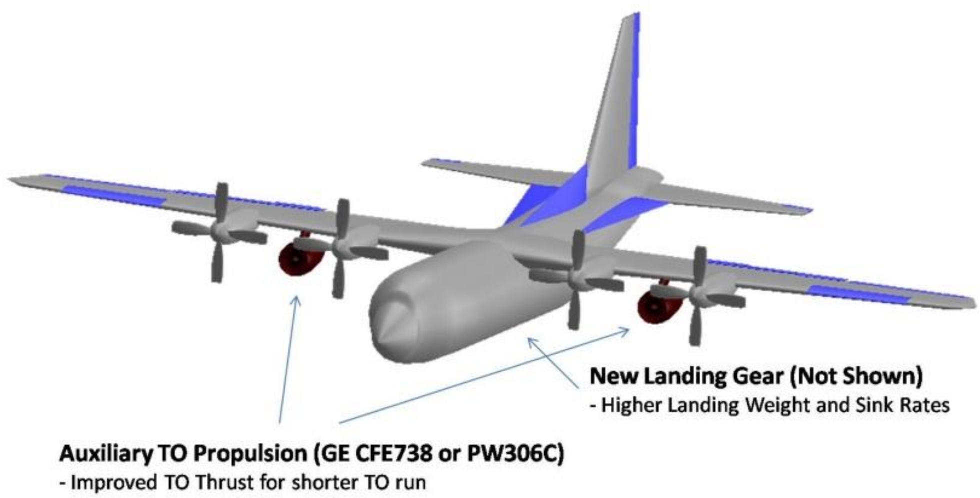


Figure 21: New Landing Gear and Auxiliary Propulsion

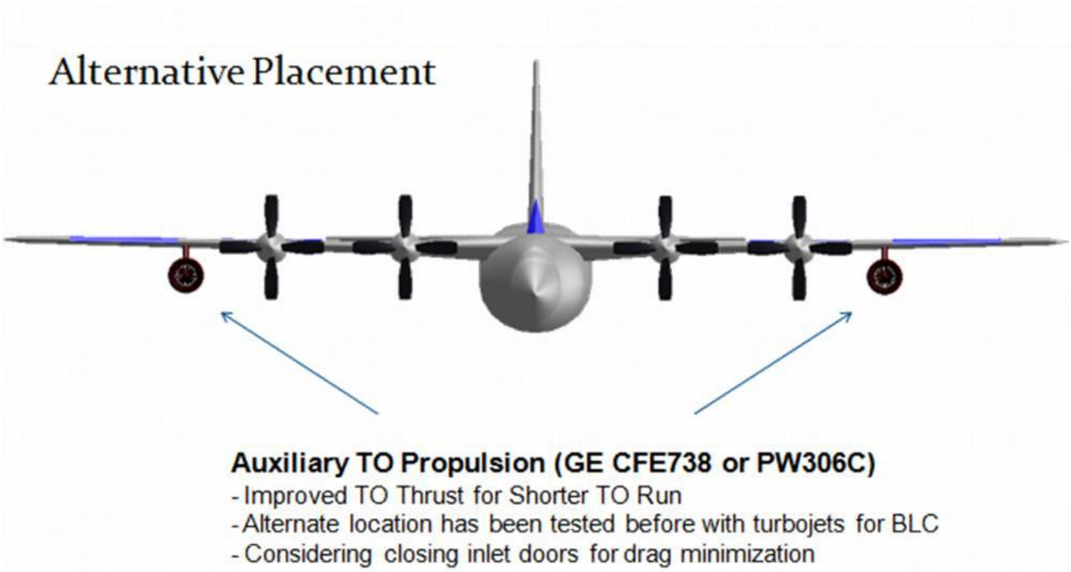


Figure 22: Auxiliary Propulsion Alternative Placement

Since the basic purpose of each of the modifications is understood, the next step is to quantify the effects of these changes on the takeoff and landing performance of the MedWing C-130. However, in order to do this, the performance drivers of the standard, stretched, and HTTB versions of the C-130 must first be uncovered, using existing knowledge as the starting point. This process is detailed in the following section.

Reverse Engineering the C-130

Much of the research effort behind this thesis has involved the search for data. Unfortunately, many important engineering parameters (such as $C_{L,Max}$ and $C_{L,TO}$) are not published and thus have to be reverse-engineered from whatever data is available. Though this may seem like a "shot in the dark," reasonably accurate data can be obtained readily using fundamental engineering logic, as long as it is applied with the proper amount of care. This endeavor and the methodology behind it are explained herein:

Baseline Estimates: C-130H

Many of the C-130H specifications, including data imperative to performance studies, is published in renowned aircraft encyclopedias, such as Jane's All The World's Aircraft. (13) The relevant data are shown in Table 3 below:

Table 3: C-130H Parameters (13)

Parameter	Magnitude	Units	Notes
MTOW	155,000	lbs	
S	1745	ft^2	
VSTALL	100	kts	(At MTOW = 155,000 lbs)
	168.78	ft/sec	
TO run	3580	ft	(Ground Run)
TO to 15 m (50 ft)	5160	ft	(TO Field Length)
Landing from 15 m (50 ft)	2400	ft	(At LW = 100,000 lbs)
Landing from 15 m (50 ft)	2750	ft	(At LW = 130,000 lbs)
Landing run	1700	ft	(At 130,000 lbs AUW)
Engine SHP	4508	shp	(SHP per engine)
Jet Exhaust Thrust	800	lbs	(jet thrust per engine) (22)

These data are used to obtain the maximum and takeoff lift coefficients of the C-130H via the lift equation from earlier, assuming that V_{TO} is $1.2V_{STALL}$ (as dictated by current safety standards in order to prevent stall on takeoff), that control surface deflection does not increase S, and that standard sea-level atmospheric conditions exist:

$$L = \frac{1}{2}\rho V^2 SC_L \Rightarrow C_L = \frac{L}{\frac{1}{2}\rho V^2 S}$$

$$\therefore C_{L,Max} = \frac{W}{\frac{1}{2}\rho V_{STALL}^2 S} = 2.62\ ;\ C_{L,TO} = \frac{W}{\frac{1}{2}\rho (1.2V_{STALL})^2 S} = 1.82$$

Thus, the takeoff lift coefficient of the C-130H can be used as a baseline value for later calculations and projections.

Next, the takeoff thrust must be determined. Ordinarily, this is no simple matter, as all of the forces on the aircraft (especially, lift, drag, rolling friction, and thrust itself) are varying as the aircraft accelerates to takeoff speed. (23) To further complicate matters, the C-130 uses a turboprop engine (which is still a jet engine, except that most of the energy output of the engine goes into driving the propeller rather than exhausting hot gas), whose propeller thrust and propeller efficiency can be very sensitive to the velocity of the oncoming air.

However, reasonable estimates of takeoff thrust can be obtained by assuming a constant, average thrust acting on the aircraft throughout its takeoff run, which is generally taken to be the value of thrust at 0.7 V_{TO} ($T(0.7V_{TO})$). Furthermore, the C-130 propellers are of the variable pitch, constant-speed type, meaning that the angle of the blades is continuously adjusted in order to maintain uniform propeller efficiency and thrust throughout the takeoff run. Moreover, in many cases, for a first-cut analysis like the one at hand, drag and rolling friction can be neglected, as they together amount to about 10 % of the takeoff thrust (in general). (23) Therefore, a simple equation can be used to make a preliminary estimate of the average takeoff thrust (which is the work-kinetic energy theorem from classical physics). (23) This equation is shown below for the C-130H:

$$Fs = \frac{1}{2}mV^2 \Rightarrow F = \frac{mV^2}{2s}$$

$$\therefore T(0.7V_{TO}) = F_{effective} = \frac{mV_{TO}^2}{2s} = 27{,}578\ lbs$$

In order to gauge the accuracy of this method and the above value, a second method is used for verification. This method is detailed by the Stanford University Department of Aeronautics and Astronautics (24). It is based on the thrust required to meet Federal Aviation Regulation (FAR) takeoff field length (TOFL) requirements (field length includes both ground roll and distance along the ground covered by the aircraft during rotation, transition, and climb segments of the takeoff), based on a given aircraft configuration. These relationships are shown in Figure 23 below:

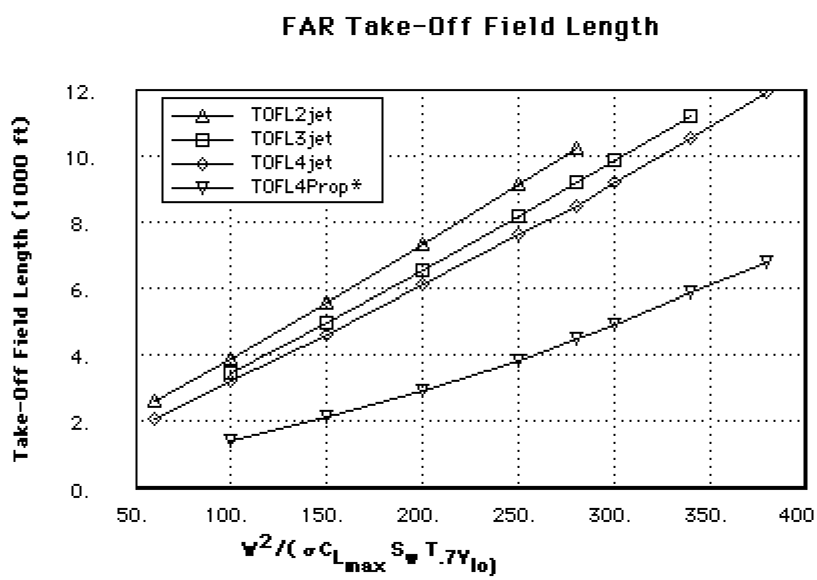


Figure 23: FAR Takeoff Field Length

The value shown on the abscissa of this plot is called the Index, which describes a given aircraft configuration. Based on a given value of TOFL, the Index can be determined using this plot, assuming the same C-130H values used previously (in this case, Stanford considers $C_{L,Max}$ to be the $C_{L,TO}$ used in the present thesis). Thus, the Index value is 310 and the FAR TOFL is assumed to be the listed C-130H TOFL of 5160 ft (even though this is a military TOFL and not a FAR TOFL). This yields an average thrust value of 24,387 lbs for a four-engine turboprop aircraft. This value is very similar to the 27,578 lbs calculated earlier, thereby validating the estimate and the prior method.

Baseline Estimates: L-100-20 & -30

Since the HTTB was an L-100-20, understanding the baseline performance characteristics of the L-100-20 & -30 aircraft (where the -20 and -30 perform similarly) was deemed crucial. The published parameters of these configurations are shown in Table 4 below:

Table 4: L-100-20 & 30 Parameters

Parameter	Magnitude	Units	Notes
MTOW	155,000	lbs	
S	1745	ft2	
VSTALL	100	kts	(At MTOW = 155,000 lbs)
	168.78	ft/sec	
FAR TO Field Length	6250	ft	
Engine SHP	4508	shp	(SHP per engine)
Jet Exhaust Thrust	800	lbs	(jet thrust per engine) (22)

According to the Stanford methodology, the FAR TOFL contains a 15 % markup for safety, which, if removed, yields a raw TOFL of 5435 ft. Furthermore, this method states that takeoff ground run generally comprises 80 % of the raw TOFL. This leads to an estimated ground roll of 4348 ft for the stretched C-130 variants. This takeoff roll can be used to reverse-engineer V_{TO} using the work-kinetic energy theorem from above. The thrust is assumed to be the same as that of the C-130H, as the engines have the same power rating. This leads to a V_{TO} of 132 kts (223 ft/sec), which leads to a $C_{L,TO}$ of 1.50 for the stretched civilian configurations. Additionally, using the Stanford FAR TOFL method highlighted above, the $T(0.7V_{TO})$ is determined to be 25,504 lbs, indicating again that the methodology at hand will yield reasonable estimates.

The data for both baselines can now be used in conjunction with the data for aerodynamic and propulsive improvements in order to make projections for the MedWing aircraft. Thus, the data for aerodynamic and propulsive upgrades must now be obtained.

High-Technology Testbed (HTTB) Aerodynamics Upgrade Data

Calculating the requisite parameters and the corresponding performance benefits for the HTTB is a bit more elusive, as very little information on the program or the test results is available publicly. Nevertheless, two important pieces of information have been published, and were used as a basis for the remainder of the initial study:

1. Based on the 1985 flight test described previously, it can be seen that the HTTB took off in 1401 ft of runway, based on a reduced takeoff weight of 98,600 lbs. It is unclear to what degree the aircraft was modified at this point. (13)
2. “Wind tunnel testing indicated that external modifications [as described in Phase I] could offer an increase in lift of up to 95 per cent.” This was stated of the modifications completed by 1988. (13)

The two items seem to indicate that not all of the modifications were flight-tested in 1985, but that all of the modifications together could produce up to a 95 % increase in lift (meaning takeoff lift coefficient). Such a value is not unreasonable, as the high-lift methods of Raymer and Corke show (these will be highlighted in greater detail later in the thesis). Thus, in order to gauge the spectrum of performance benefit (mainly, reduction in ground roll), Item #1 is used to quantify the lower bound of performance benefit, while Item #2 is used to predict the upper bound.

Using the methods highlighted previously (Work-KE equation and Lift Equation) in conjunction with the Item #1 data, V_{TO} and $C_{L,TO}$ are determined to be 94 kts (159 ft/sec) and 1.95, respectively. Thus, the lower bound percentage improvement in $C_{L,TO}$ is determined to be 29.9 %, based on the original L-100-20 $C_{L,TO}$. The same percentage improvement would lead to a new $C_{L,TO}$ of 2.37 for the C-130H.

The upper bound percentage improvement is assumed to be the 95 % increase discussed under Item #2 above. This would lead to a new $C_{L,TO}$ of 2.92 for the stretched configurations and 3.55 for the C-130H.

Propulsive Upgrade Data

Assuming an additional 12,000 lbs of takeoff thrust (6,000 lbs per additional small engine) for each configuration, the average takeoff thrust for each configuration is increased to 39,579 lbs.

MedWing Configuration Performance Sensitivity

Based on the above upgrades and equations, the design points for possible MedWing configurations are summarized in Table 5 below:

Table 5: MedWing Solution Design Points

Configuration	*CL_TO*	*F_effective/ AVG TO Thrust (lbs)*	*Ground Run, s (ft)*
L-100-20&30, Baseline	1.50	27,579	4348
L-100-20&30, STOL I (Lower Bound)	1.95	27,579	3348
L-100-20&30, STOL I (Upper Bound)	2.92	27,579	2230
L-100-20&30, STOL II (Lower Bound)	1.95	39,579	2333
L-100-20&30, STOL II (Upper Bound)	2.92	39,579	1554
C-130H, Baseline	1.82	27,579	3580
C-130H, STOL I (Lower Bound)	2.37	27,579	2756
C-130H, STOL I (Upper Bound)	3.55	27,579	1836
C-130H, STOL II (Lower Bound)	2.37	39,579	1921
C-130H, STOL II (Upper Bound)	3.55	39,579	1279

STOL I *= Aerodynamics Modifications ONLY;* ***STOL II*** *= Aerodynamics AND Propulsive Modifications*

These design points are plotted in Figure 24 below, in order to gauge the sensitivity of takeoff ground roll to both aerodynamics and propulsive upgrades:

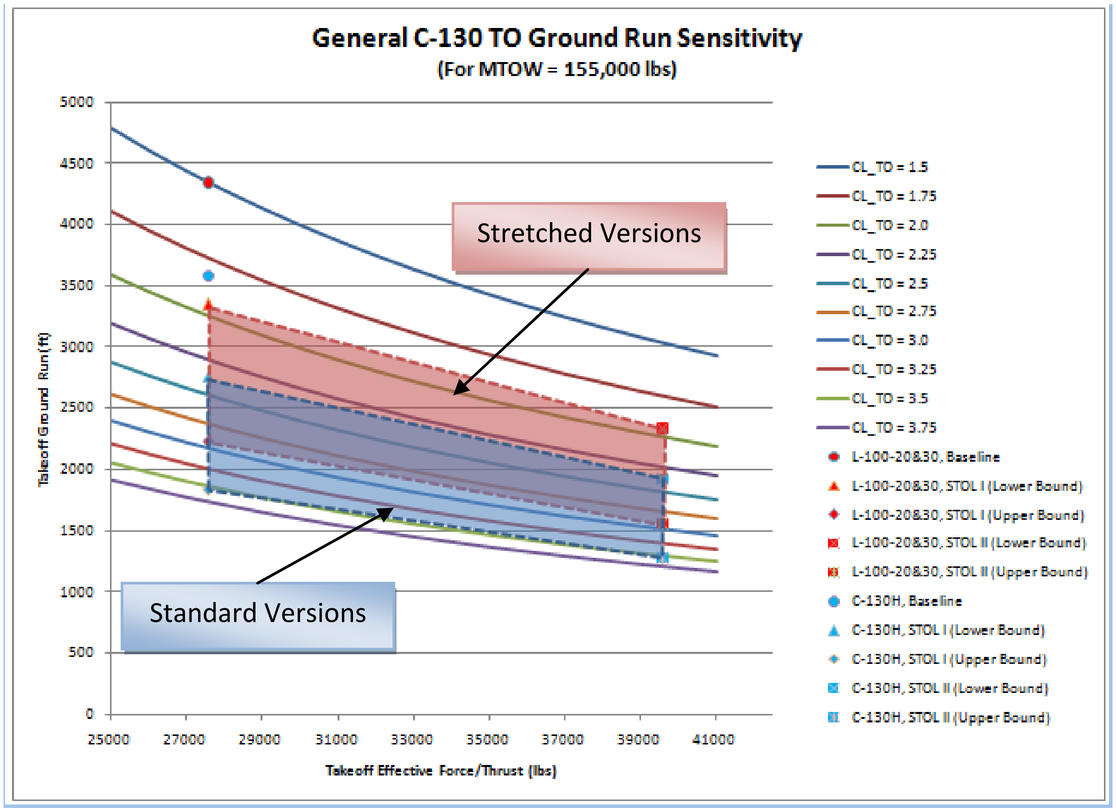


Figure 24: Takeoff Ground Run Sensitivity

From the design points described, performance ranges were constructed for a variety of aerodynamic and propulsive settings, as denoted by the $C_{L,TO}$ curves and increasing propulsive axis. Thus, it can be seen that, as $C_{L,TO}$ and thrust are increased, takeoff run is decreased. Most likely, the MedWing C-130 performance will fall somewhere in between these performance ranges (depending on the variant chosen). Ideal performance values for the C-130H are shown in Table 6 below. These values must be verified with more detailed analysis in order to get a better perspective on how exactly the MedWing C-130 will perform.

Table 6: Ideal Performance Values for MedWing (C-130H)

Parameter	**Baseline (C-130H)**	**Aerodynamics Modification**	**Aero & Propulsive Modification**
$C_{L_{TO}}$	1.8	2.4-3.6	(2.4-3.6)
Average TO Thrust *(lbs)*	27,000	(27,000)	39,500
TO Ground Run *(ft)*	3,580	1,800-2,700	< 1,500

MedWing Modifications, Phase II: Detailed Systems Integration Analysis

Overview

The projections made in the previous section appear to be very promising: Indeed, the potential benefits afforded by the modifications proposed in Phase I would lead to far greater access to people in need. However, the projected improvements are based on reverse engineering of existing configurations and tested technologies. Thus, it is now time to verify the performance benefits through more enhanced analysis techniques. These are listed as follows:

1) Corke's High-Lift System Method
2) Raymer's High-Lift System Method
3) Computational Fluid Dynamics (CFD) Simulation

Furthermore, two airfoil/wing analysis tools, DesignFOIL and JavaFoil, were used in conjunction with the Raymer and Corke techniques in order to determine certain critical parameters for basic airfoil and wing configurations. However, the C-130 wing had to be reverse engineered prior to using these techniques, in order to determine the wing cross-sectional geometry (airfoil sections). These techniques and the results yielded by them are discussed in greater depth throughout this chapter.

Reverse Engineering the C-130 Wing

Only a few details are available regarding the geometry of the C-130 wing. However, these data, along with a scaled three-view drawing of the aircraft, are enough to determine a full definition of the detailed wing geometry with reasonable accuracy. The available data are summarized in Table 7 below:

Table 7: C-130H Wing Design

Parameter	Value
Wing Span	132' 7"
Root Airfoil	*NACA 64A-318*
Tip Airfoil	*NACA 64A-412*
Root Incidence Angle	3 degrees
Tip Incidence Angle	0 degrees
Dihedral Angle	2.5 degrees

These data can be used in conjunction with the scaled drawing in order to estimate the remaining parameters, since known dimensions can be used to estimate unknown dimensions, as shown in Figure 25, Figure 26, and Table 8 below:

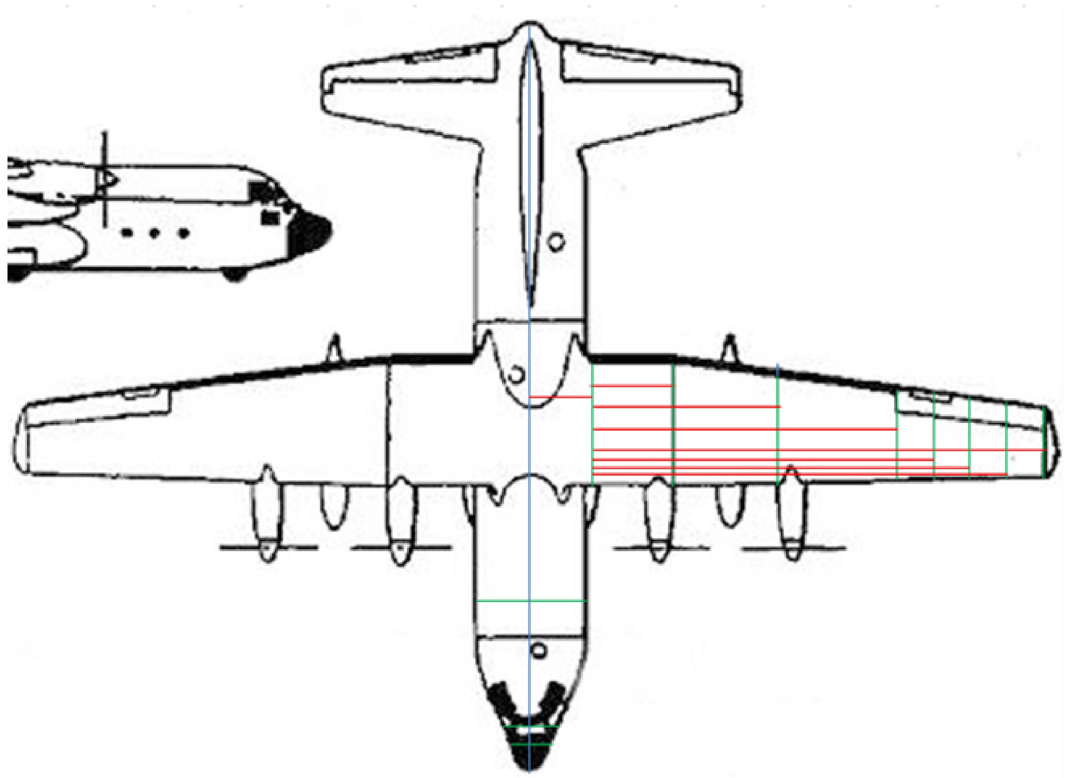


Figure 25: C-130H Scaled Drawing, Planform View

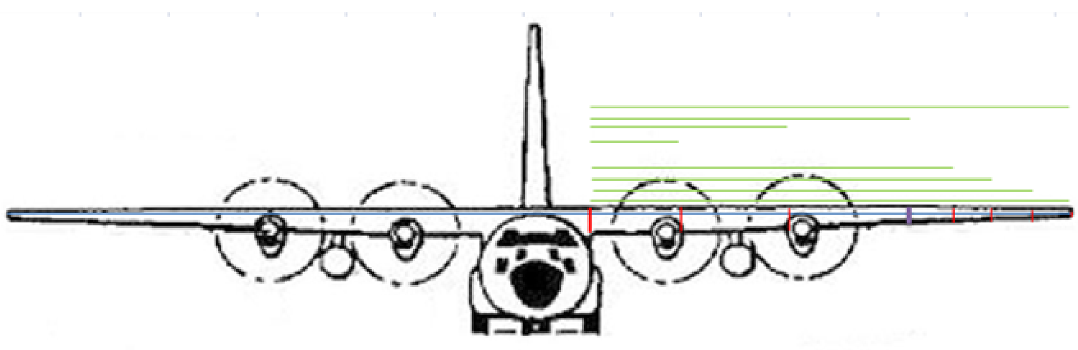


Figure 26: C-130H Scaled Drawing, Front View

Table 8: C-130H Determined Wing Geometry

STATION	Distance from Root, y (ft)	Local Chord, c (ft)	Thickness, t (ft)	Thickness-to-chord, t/c (%)	Airfoil
0 (*ROOT*)	0.00	16.12	2.98	18.51	*NACA 64A-318*
1	10.98	16.12	2.98	18.51	*NACA 64A-318*
2	24.52	14.23	2.65	18.63	*NACA 64A-318*
3	39.79	11.66	1.99	17.05	*NACA 64A-417*
4 (*TIP*)	59.68	9.26	1.16	12.53	*NACA 64A-412*

Based on the thickness-to-chord data, the airfoils were determined as shown. These data were then used to obtain basic airfoil and wing properties from JavaFoil and DesignFoil.

A Note on Reynold's Number

In Aerospace Engineering, it is convenient to express many important parameters in a nondimensionalized format, so as to gauge the relative behaviors of certain geometric configurations (recall lift coefficient from the previous discussions). Another such parameter exists called the Reynold's Number. Reynold's Number is a somewhat difficult concept to explain, but in short, it is a ratio of inertia forces to viscous forces acting on a body in a fluid flow. This basically relates the momentum and energy of the flow (which are related to its inertial properties) to its frictional effects (expressed through viscosity). This can be seen in the following equation:

$$Re = \frac{\rho V^2 L}{\mu}$$

where ρ is the density of the oncoming fluid, V is the velocity of the oncoming fluid, L is a characteristic length describing the object in the flow, and μ is the viscosity of the fluid.

In order to gauge the relative energy of a particular fluid flow around or through a body, Reynold's Number can be calculated. Thus, low Reynold's Numbers indicate relatively low-energy flows, and high Reynold's Numbers indicate relatively high-energy flows, which tend to follow the contours of a particular object better than do low-Re flows, meaning that they stay attached to the body. This concept is useful in the analysis of airfoils, wings, and high-lift devices (such as those discussed in Phase I), since attached flow is desirable on said bodies, especially in low-speed (low-energy) conditions (recall the leading edge extensions discussed before).

At present, it is necessary to determine the Reynold's Numbers experienced by the airfoil sections determined in the previous sections, in order to perform analysis using the correct flight conditions. Since the focus of the present aerodynamics study is takeoff performance of the wing, takeoff condition Reynold's Numbers must be determined for the C-130 wing sections. The range of Reynold's Numbers for a "clean" wing (meaning "without control surfaces or propeller effects") fall between the values experienced at the root and tip airfoils, respectively. These are determined as follows:

$$Re_{Root} = \frac{\rho_{SL} {V_{TO}}^2\, c_{Root}}{\mu_{SL}} = \frac{\left(0.002378\ \frac{slugs}{ft^3}\right)\left(202.54\ \frac{ft}{sec^2}\right)^2\ (16.12\ \text{ft})}{\left(0.000000362\ \frac{lb-sec}{ft^2}\right)} = 21{,}447{,}556.46$$

$$Re_{Tip} = \frac{\rho_{SL} {V_{TO}}^2 c_{Tip}}{\mu_{SL}} = \frac{\left(0.002378\ \frac{slugs}{ft^3}\right)\left(202.54\ \frac{ft}{sec^2}\right)^2\ (9.26\ \mathrm{ft})}{\left(0.000000362\ \frac{lb-sec}{ft^2}\right)} = 12{,}320{,}936.69$$

These values will play an important role in the following as well as later analyses.

JavaFoil Analysis

JavaFoil is an interactive aerodynamics prediction software used to determine the characteristics of basic 2-dimensional wing cross-sections (known as airfoils). Airfoil flow is considered 2D because the flow should theoretically vary in only two directions (along the length and height of the cross-section) and be constant in the spanwise (depth-wise) direction. This software uses a panel-based numerical flow solver code similar to that of XFoil (another famous software in this genre). (25) The details of this analysis are presented below:

Airfoil Coordinate Generation

Thousands of airfoil coordinate geometries are available as part of online database resources. This, however, is not the case for the C-130 airfoils. Thus, the coordinate geometries were generated using JavaFoil's Airfoil Geometry tool. An example is shown in Figure 27 below:

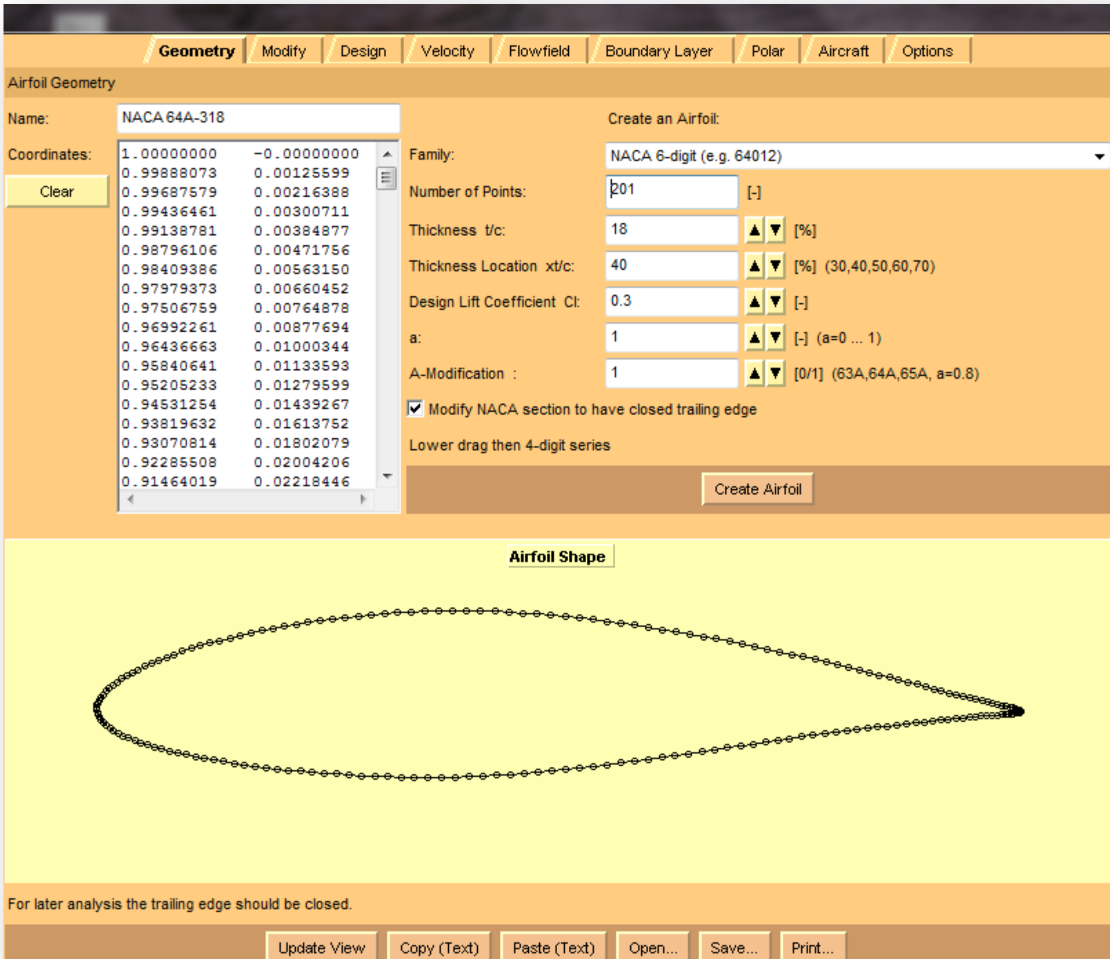


Figure 27: Example of JavaFoil Airfoil Geometry Generation (NACA 64A-318)

This geometry can now be exported to other analysis tools.

Estimation of 2D Lift-Curve Slope and Zero-Lift Angle of Attack

Understanding how the aerodynamic lift coefficient (C_l) varies with angle of attack (α) will help lead to an understanding of how lift varies with angle of attack for the full wing. Thus, the 2D lift-curve slope ($dC_l/d\alpha$) must somehow be determined. Historically, this has been done through wind tunnel testing of airfoils, which has led to the vast databases mentioned before. However, since no such data was readily available for the C-130 airfoils, the use of an alternate method became imperative.

This is where JavaFoil is useful. As mentioned previously, JavaFoil can be used to solve fluid flow equations around an airfoil. Thus, studies were performed inside JavaFoil, in which lift coefficient and zero-lift angle of attack (α_{L0}) were calculated for various angles of attack across different ranges of Reynold's Numbers. Example lift curves are shown in Figure 28 and Figure 29 below:

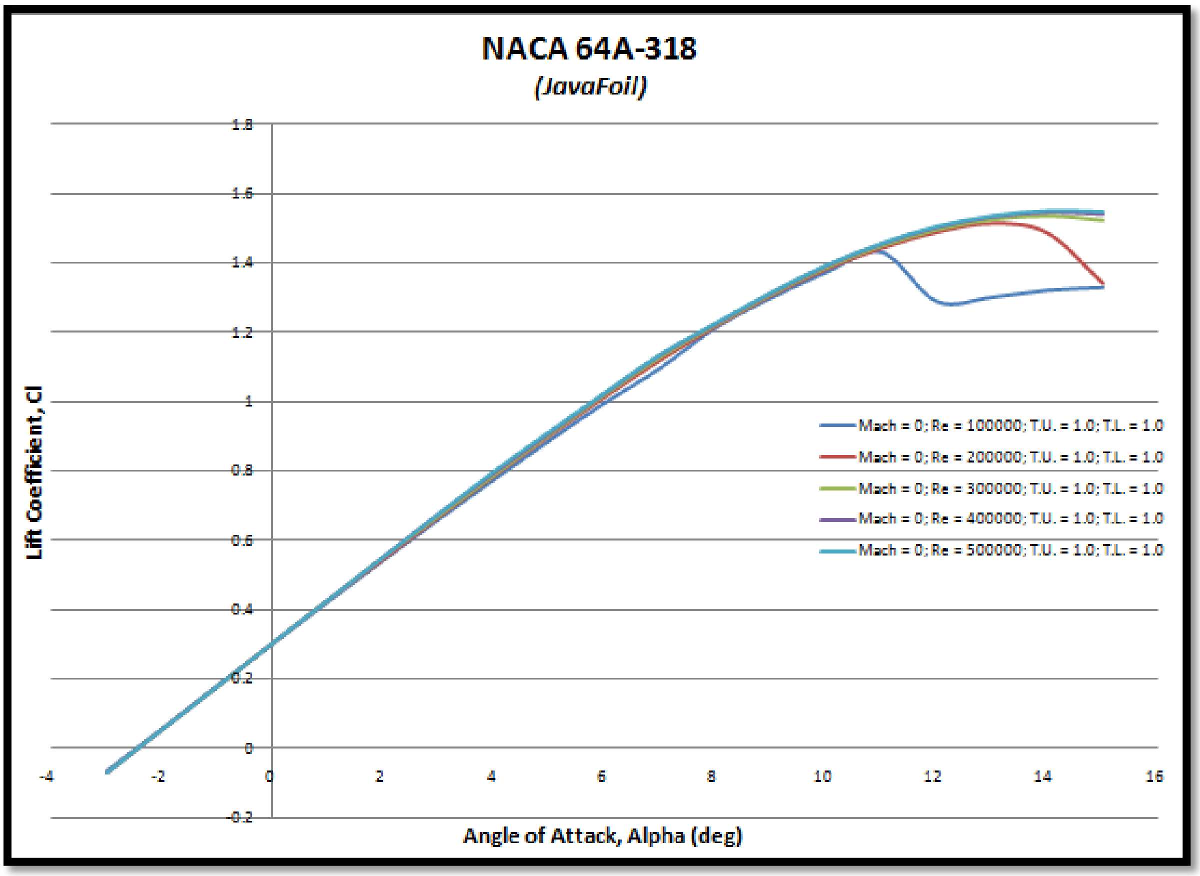


Figure 28: NACA 64A-318 Lift Curve, Re = [100,000 - 500,000]

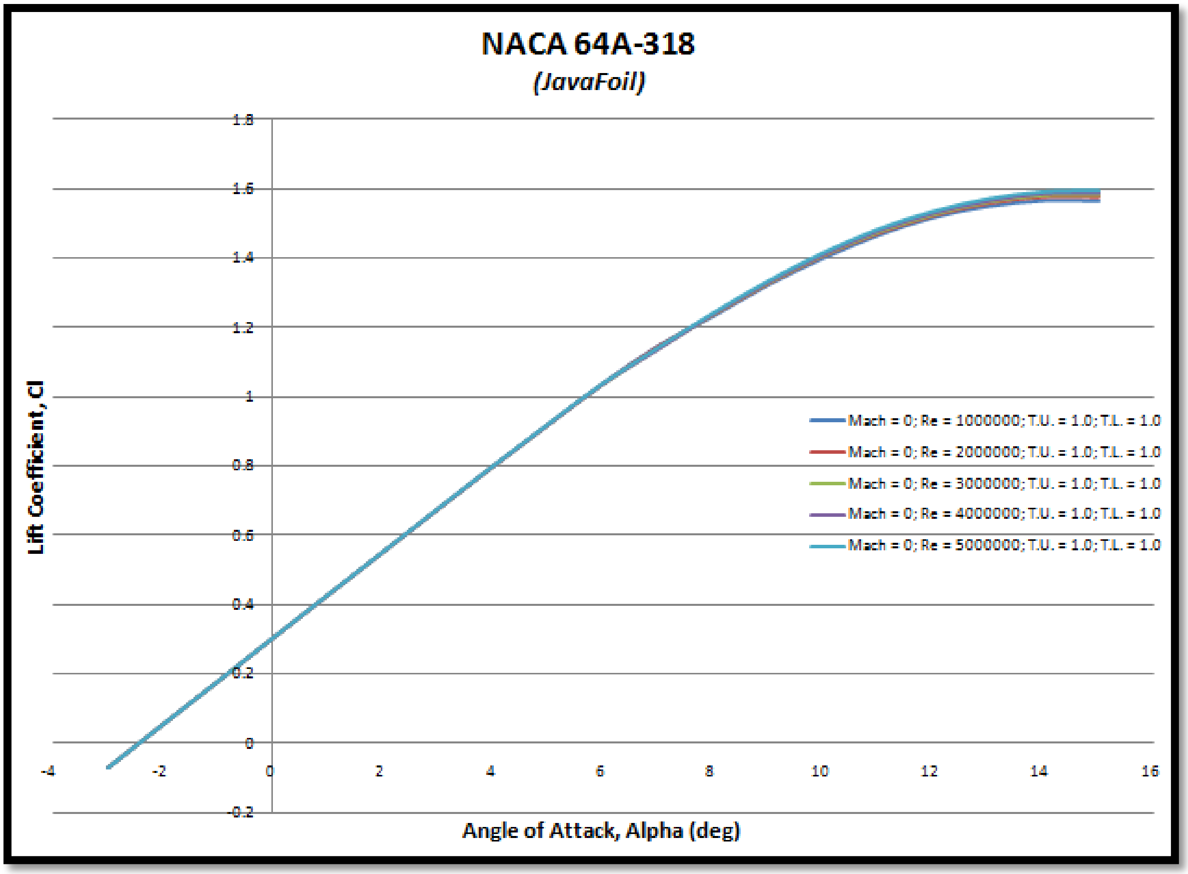


Figure 29: NACA 64A-318 Lift Curve, Re = [1,000,000 – 5,000,000]

The results of the JavaFoil study are summarized in Table 9 below. It should be noted that for all three airfoils, the respective lift-curve slope values rapidly converge with increasing Reynold's Number to the values listed, as do the respective zero-lift angle of attack values:

Table 9: C-130 Airfoil Lift Curve Parameters (JavaFoil)

Airfoil	Lift-Curve Slope ($dC_l/d\alpha$)	Zero-Lift Angle of Attack (α_{L0})
NACA 64A-318	0.124	-2.468
NACA 64A-417	0.123	-3.276
NACA 64A-412	0.119	-3.235

These results can now be used with other analysis techniques and will be especially useful in determining the 3-dimensional properties of the wing.

DesignFOIL Analysis

A second useful analysis tool is DesignFOIL, which is another interactive aerodynamics software. However, DesignFOIL differs from JavaFoil in that it is also capable of performing 3-dimensional flow analysis on somewhat detailed wings, which are built up from airfoil sections specified by the user. (26) At present, DesignFOIL has been used to determine the 2D performance of the airfoil sections (in order to check whether these data match with the airfoil data obtained via JavaFoil in the previous section), as well as to run 3D analysis on a basic, "clean" (meaning "without control surfaces or propeller effects") C-130 wing built up from the airfoil sections determined during prior analysis. Both the 2D and 3D data determined here are used in the high-lift analysis techniques, to be discussed soon. But first, an in-depth look at the DesignFOIL analysis:

Estimation of 2D Lift-Curve Slope and Zero-Lift Angle of Attack

As stated before, understanding the 2D behavior of the wing sections can lead to a better understanding of the complete wing behavior (3D). However, because of the potential difficulties associated with this, it is important to use a different method to verify the results of a given airfoil study. Thus, DesignFOIL was used to verify the JavaFoil 2D data. To do this, the airfoil coordinate geometry generated by JavaFoil was imported into DesignFOIL and subsequently analyzed using DesignFOIL's "Virtual Wind Tunnel" tool. An example DesignFOIL lift-curve plot is shown in Figure 30 below and the results of the 2D aerodynamics study are summarized in Table 10 below:

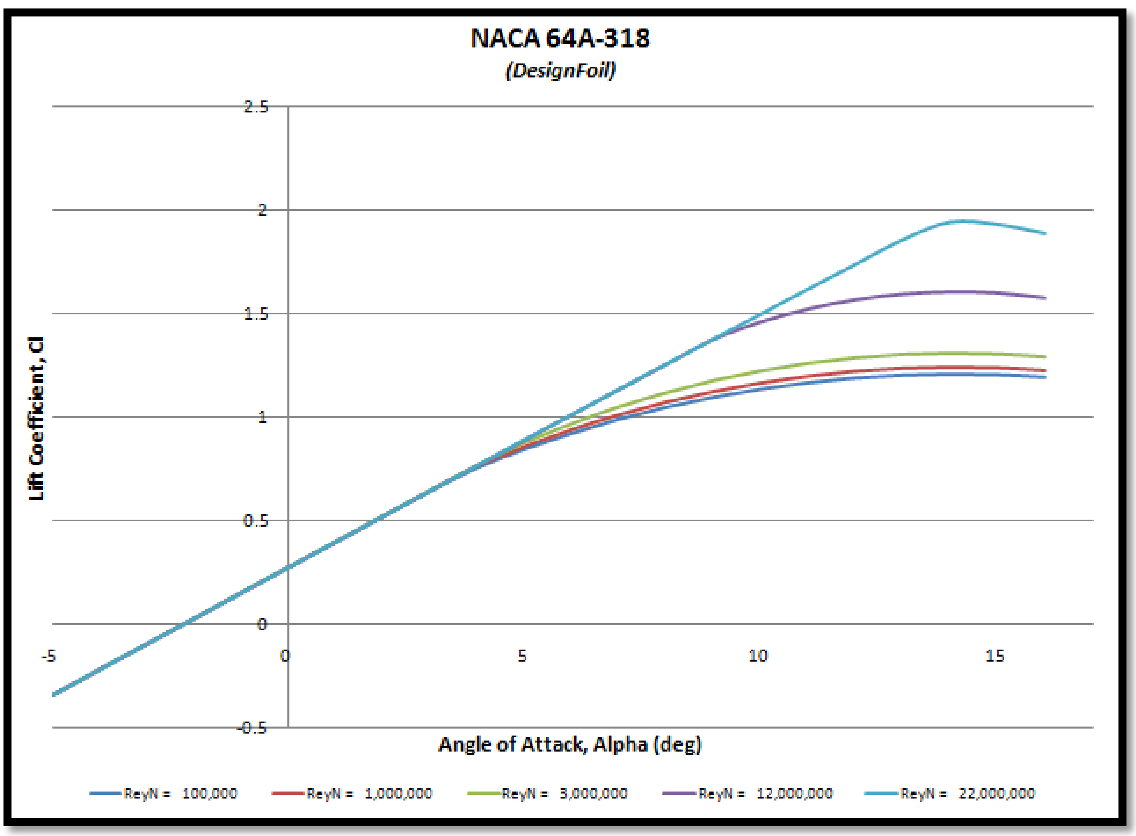


Figure 30: NACA 64A-318 Lift Curve,
Re = [100,000; 1,000,000; 3,000,000; 12,000,000; 22,000,000] (DesignFOIL)

Table 10: C-130 Airfoil Lift Curve Parameters (DesignFOIL)

Airfoil	Lift-Curve Slope ($dC_l/d\alpha$)	Zero-Lift Angle of Attack (α_{L0})
NACA 64A-318	0.123	-2.260
NACA 64A-417	N/A	N/A
NACA 64A-412	0.118	-3.025

The lift-curve data obtained via DesignFOIL show good agreement with the JavaFoil data (it should be noted that said data could not be obtained for the NACA 64A-417 airfoil, as the geometry was not deemed acceptable by the Virtual Wind Tunnel: It is likely that some of the coordinates associated with the geometry file caused numerical problems in the flow solver, resulting in irreconcilable errors. However, this is likely more of a mathematical issue rather than a physical one, and thus the analysis was continued without this additional data). Therefore, more confidence can now be placed in the 2D data, as it has been verified by two separate sources and methods. The choice of Reynold's Numbers for these tests will be discussed momentarily.

Estimation of 3D Lift-Curve Slope and Zero-Lift Angle of Attack

DesignFOIL offers distinct advantages over other panel codes in that full, 3-dimensional wing geometries can be tested in the Virtual Wind Tunnel (a wing is considered to have 3D flow because both the wing and flow properties vary in the spanwise direction). Thus, the wing is built up from the imported airfoil geometries as well as the actual physical dimensions of the wing using DesignFOIL's WingCrafter tool (this geometry can later be exported into SOLIDWORKS for even more analysis, to be highlighted soon). The basic C-130 wing constructed in the WingCrafter is shown in Figure 31 below:

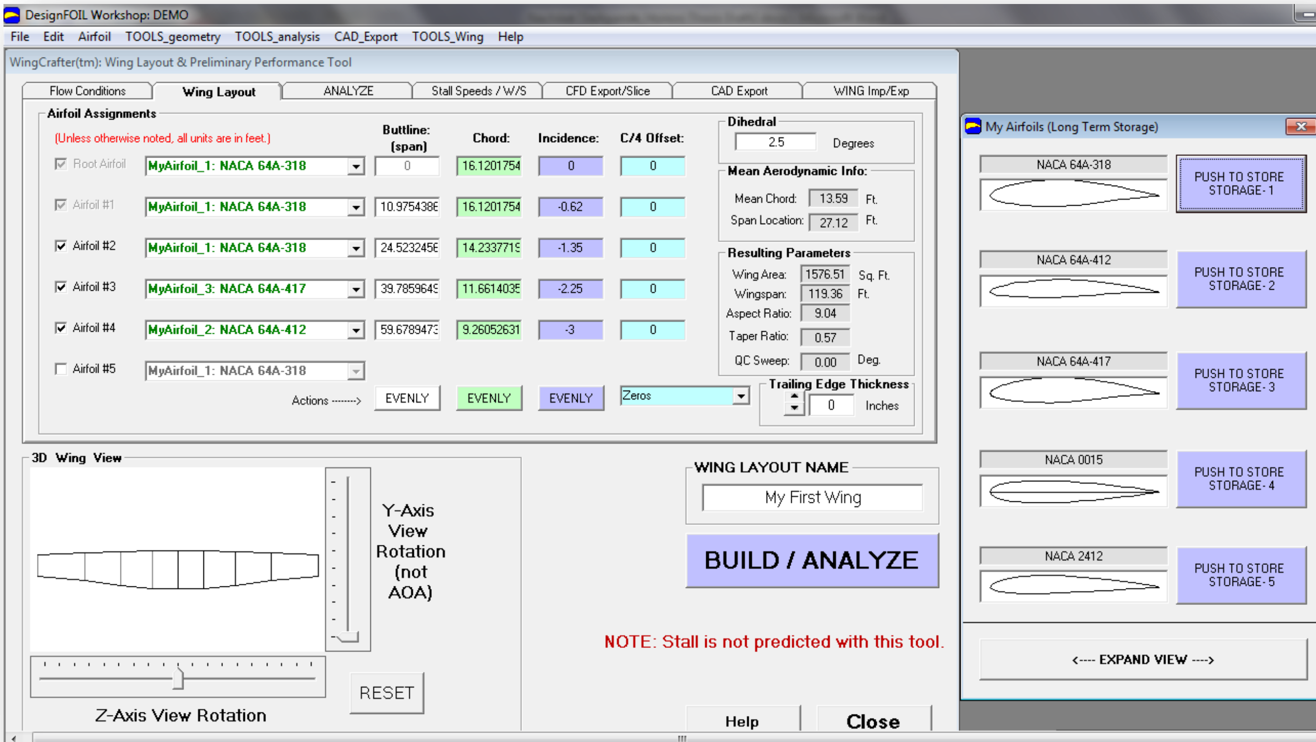


Figure 31: DesignFOIL WingCrafter 3D C-130 Wing

Virtual Wind Tunnel analysis was run on this wing based on the takeoff velocity (V_{TO} = 202.5 ft/sec, M = 0.18) and root Reynold's Number from above. The angle of attack was varied until the 3D lift-curve data were obtained, as shown in Figure 32 below:

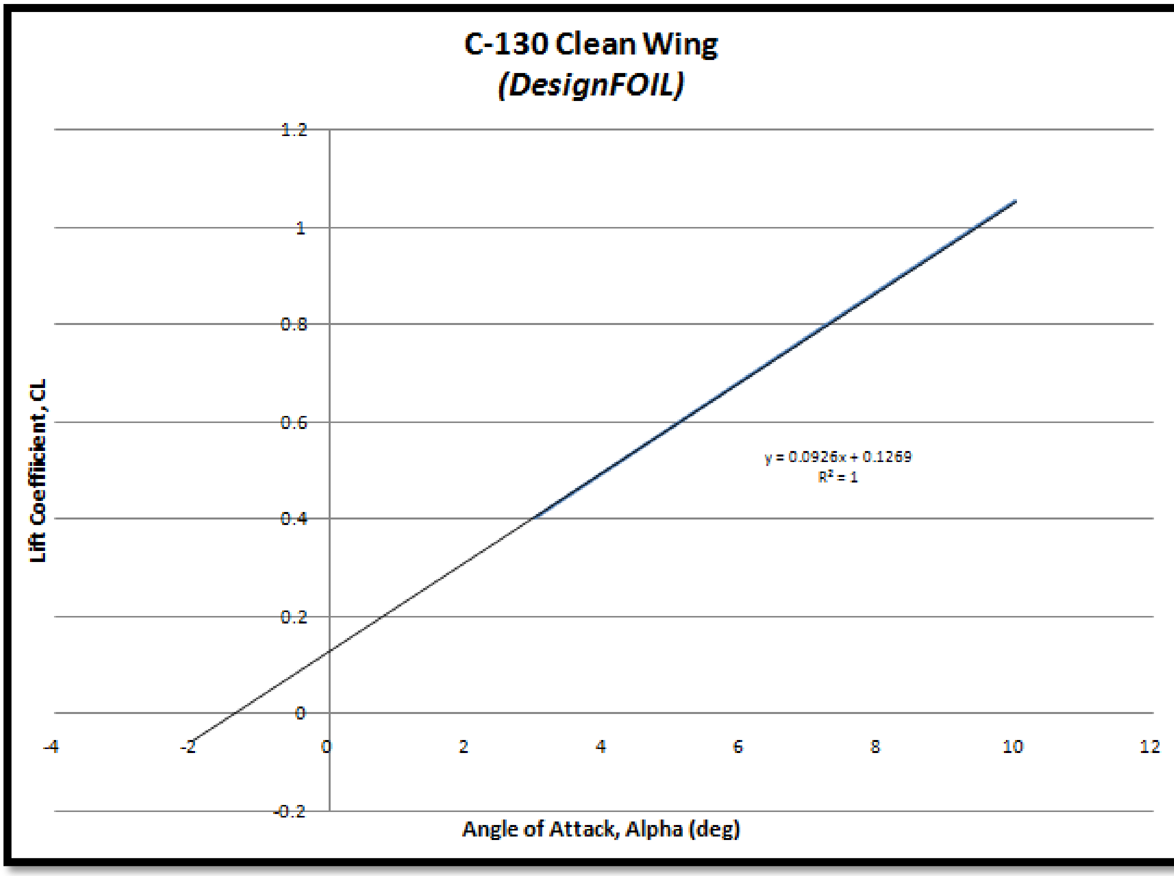


Figure 32: Lift Curve, C-130 Clean Wing (DesignFOIL)

It should be noted that DesignFOIL places a limit of 10 degrees on angle of attack (hence, the lift-curve data do not extend past α = 10 degrees). The 3D lift-curve data are shown in Table 11 below:

Table 11: C-130 Clean Wing Lift Curve Parameters (DesignFOIL)

Wing	Lift-Curve Slope ($dC_L/d\alpha$)	Zero-Lift Angle of Attack (α_{L0}, Root)
C-130, clean	0.093	-1.3

The lift-curve slope for the wing is somewhat lower than that of the airfoils comprising the wing, as expected, since the lift-curve slopes of 3D clean wings are generally lower than those of the airfoils that make them up (due to the finite lengths of wings and the induced wingtip vortex drag thereof). (23) These data can now be used in conjunction with high-lift techniques in order to determine the effects of flaps and leading edge extensions on the C-130 wing.

High-Lift Analysis Technique 1: Corke's High-Lift Method

Dr. Thomas C. Corke is a professor of Aerospace Design and Fluid Mechanics at Notre Dame University. His book, *Design of Aircraft*, has been invaluable in light of the present project, as his high-lift method, based on historical trends in high-lift system effects, is very applicable to aircraft engineering studies, whether they involve conceptual design or performance modifications. Furthermore, the technique involved herein deals directly with high-lift system performance trends observed from years and years of aerospace development, as opposed to the particular high-lift devices of the configurations reverse-engineered and projected in Phase I. (27) Thus, knowledge gained from the following technique can serve to verify the Phase I methodology. This technique is outlined below:

Step 1: Gather Wing Data

Before quantifying the effects of high-lift devices on the C-130 wing, the basic parameters of the clean wing, as required by Corke's method, must be gathered. These parameters are shown in Table 12 below:

Table 12: Wing Data Inputs, Corke's Method

Wing Data:			**Description**
Airfoil	NACA	64x	Root Airfoil = NACA 64A-318
Λ_{LE}	0	deg	Leading-edge sweep
λ	0.57		Taper ratio (C_{root}/C_{tip})
t/c	0.18		Root thickness-to-chord ratio
T-O Mach No.	0.181		Mach Number at Takeoff
β	0.98		
A	10.07355		Aspect Ratio
$\Lambda_{t/c}$	0.0	deg	
$C_{l\alpha}$ **(no flap)**	0.1235	1/deg	Root Airfoil Lift-Curve Slope (2D)
$C_{L\alpha}$ **(no flap)**	0.093	1/deg	Clean Wing Lift-Curve Slope (3D)
α_{0L}	-1.3	deg	Wing Root Zero-Lift AOA (3D)
C_{lmax}	1.7		Root Airfoil Max Lift Coeff (2D)
α_s	12.5	deg	Root Airfoil Stall Angle (2D)

The parameters listed above can be determined from geometric data (either published or reverse-engineered, as discussed previously) or from aerodynamic calculations (as discussed under prior Phase II sections). Specifically, the 2D root lift-curve slope is an average of the values determined via JavaFoil and DesignFOIL (from Table 9 and Table 10), while the 3D wing lift-curve slope and the root zero-lift angle of attack are as obtained via DesignFOIL data (see Figure 32). Furthermore, recalling the above discussion regarding Reynold's Number, it can be seen from the DesignFOIL root airfoil data (Figure 30) that C_{lmax} increases with increasing Reynold's Number. However, the creator of DesignFOIL claims that this software predicts C_{lmax} accurately only for Reynold's Number values between 90,000 and 9 million, and that C_{lmax} values around 1.6 are generally expected for airfoils. (26) However, this presents a problem to the current effort, as the C-130 root Reynold's Number calculated earlier is on the order of 21-22 million, well outside of DesignFOIL's accuracy range. What can be done about this? Clearly, an informed assumption is needed here in order to move forward. Figure 30 shows a C_{lmax} of about 1.9 for Re=22 million, which seems a bit high for an airfoil, while at Re=12 million (tip chord Re), C_{lmax} = 1.6. Thus, as a rough first-cut estimate, a true C_{lmax} of 1.7 is assumed for the root airfoil, to compensate for any overestimation. Lastly, from the same figure, the stall angle of attack (α_S) corresponding to this C_{lmax} is 12.5 degrees, which is a reasonable angle.

Step2: Calculate Flap Data

Next, the effect of each high-lift device on lifting ability can be quantified, based on flap type and flap deflection (δ_f), ratio of flapped to total wing area (S_f/S_w), ratio of flap-extended to flap-retracted chord length (c_f/c), and the data gathered in Step 1. The flap geometric data are gathered as shown in Figure 33 below and are listed in Table 13 below:

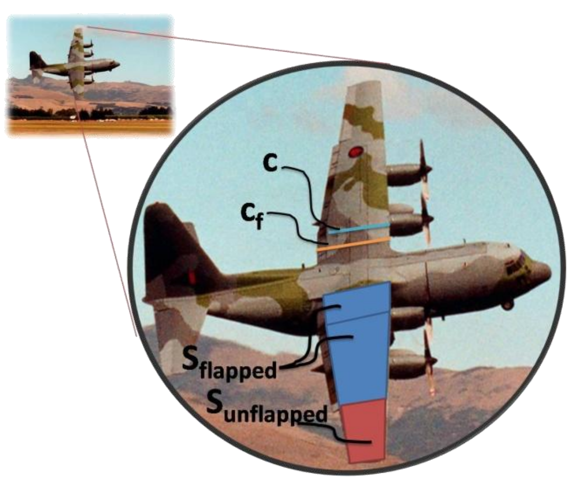


Figure 33: Flap Details

Table 13: Flap Details

Trailing-edge Flap Design:		
Flap type	slot	slot, plane or split
S_f/S_w	*0.75*	
δ_f	*40*	deg
c_f/c	*0.25*	

It should be noted that the flap deflection angle was chosen to be 40 degrees, as this is a reasonable value for the C-130. It should also be noted that the C-130H employs Lockheed-Fowler flaps and that the MedWing will use double-slotted flaps (meaning that both flap devices are of the "slotted" type, as specified in Table 13). Using Corke's method, the data gathered above are correlated with high-lift device data in order to determine the effects of the respective C-130 baseline and MedWing aerodynamics systems modifications on the wing maximum lift coefficients, as outlined in Figure 34 below:

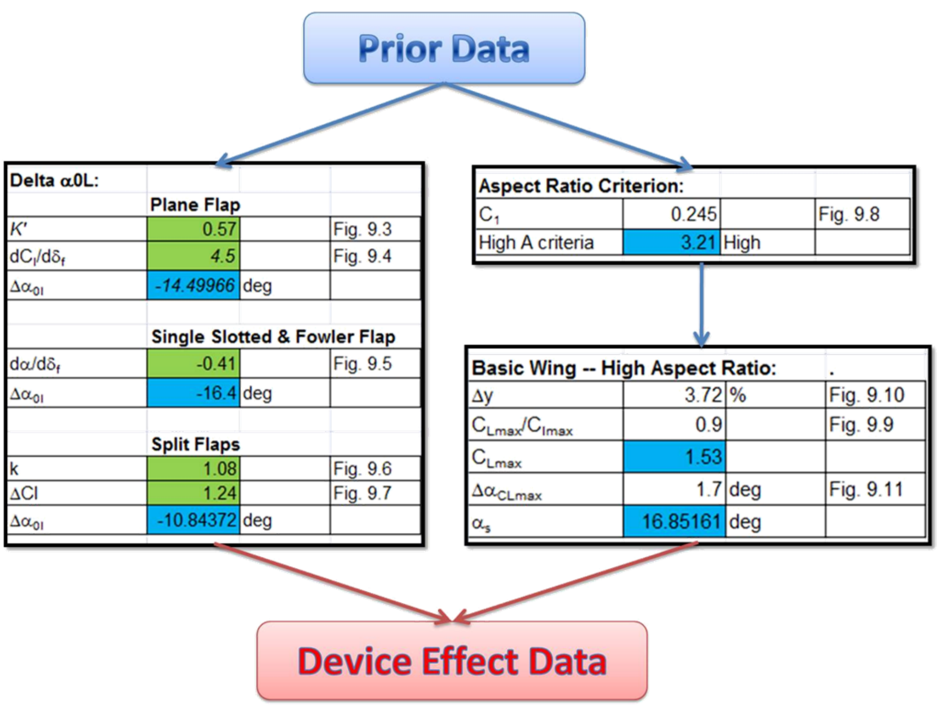


Figure 34: Corke's Method

The device effect data obtained is then used to plot lift-curve data for the trailing edge slotted flaps, as shown in Figure 35 below:

Effect of Trailing-edge Flap:			
Flap type	slot	slot, plane or split	
α_{0l}	-17.7		
Basic 3-D α_s	16.85161	deg	
Basic 3-D C_L	1.53		
2–D $\Delta\alpha_s$	-2.8	deg	Fig. 9.18
2–D $\alpha_{s\ flapped}$	9.7	deg	
$(C_{lmax})_{flapped}$	3.3839		
ΔC_{lmax}	1.6839		
$K\Delta$	0.92		
ΔC_{Lmax}	1.161891		
C_{Lmax}	2.691891		
3-D $\alpha_{s\ flapped}$	14.05161	deg	

Leading-edge flap CL Max:			
ΔC_{lmax}	0.3		Table 9.1
ΔC_{Lmax}	0.225		
C_{Lmax}	2.916891		

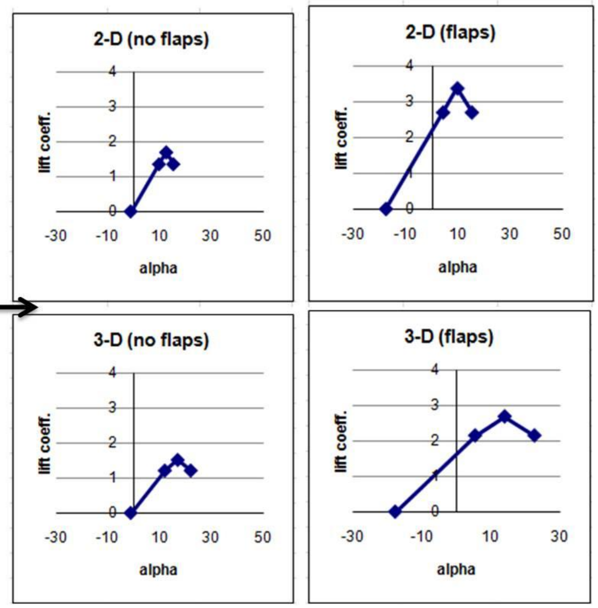


Figure 35: Corke's Method (Cont.)

The important wing parameters gleaned from this study are summarized in Table 14 below:

Table 14: Corke's Method Results

Parameter	Value
Wing C_{Lmax} (Clean)	1.53
Wing C_{Lmax} (TE Slotted Flaps)	2.69
Wing C_{Lmax} (TE Slotted Flaps + LE Device)	2.92

These results will be discussed in greater depth shortly. However, for now, it should be noted that the slotted flap prediction does not differentiate between single- and double-slotted flaps.

High-Lift Analysis Technique 2: Raymer's High-Lift Method

Dr. Daniel P. Raymer is a famous guru of aircraft design. He is reputed for his teaching of various aircraft conceptual design courses and is the author of *Aircraft Design: A Conceptual Approach*, which is a very useful resource for those in the aircraft engineering field. In this resource, he highlights a method for directly estimating the approximate lift contributions of high-lift devices. This is different from the methodology used in Phase I, as the technique deals directly with historical data on high-lift devices in general, rather than the data of particular configurations (such as the C-130 baselines and the HTTB). Thus, Raymer's method is used in this section to determine the high-lift properties of the C-130H baseline as well as the MedWing C-130 configurations.

High-Lift Device Contributions

Raymer's historic data are expressed as proportional increases in airfoil maximum lift coefficient, as shown in Table 15 below:

Table 15: Raymer High-Lift Device Contributions

HIGH-LIFT CONTRIBUTIONS	
(Table 12.2: Approximate Lift Contributions of High-Lift Devices)	
High-Lift Device	ΔC_{lmax} **(2D)**
Flaps	
> Plain and split	0.9
> Slotted	1.3
> Fowler	1.3*c'/c
> Double-slotted	1.6*c'/c
> Triple-slotted	0
Leading-edge Devices	
> Fixed slot	0.2
> Leading edge flap	0.3
> Kruger flap	0.3
> Slat	0.4*c'/c
> Leading edge extension	0.4

These contributions can now be applied at the airfoil level in order to determine 3D wing maximum lift coefficients for the baseline and modified C-130 configurations, as shown in Table 16 below:

Table 16: Raymer's Method

High-Lift Device	ΔC_{lmax}	c'/c	$S_{flapped}/S_w$	γ_{HL} (deg)	ΔC_{Lmax}	Net ΔC_{Lmax}	New C_{Lmax}
Flaps							
> Fowler (Straight)	1.625	1.25	0.25	0	0.37		
> Fowler (Swept)	1.625	1.25	0.5	3.5	0.73	1.10	2.63
> Double-slotted (Straight)	2	1.25	0.25	0	0.45		
> Double-slotted (Swept)	2	1.25	0.5	3.5	0.90	1.35	
Leading-edge Devices							
> Leading edge extension	0.4		0.4	0	0.14	0.14	3.02

Many of the parameters are as determined in the previous section for Corke's method. Also, the new 3D wing estimates are based on a clean wing C_{Lmax} of 1.53, as determined via the Corke analysis (this was necessary, as no other method was available at the time to calculate clean 3D C_{Lmax}). Also, the formula for ΔC_{Lmax} is as follows:

$$\Delta C_{L,max} = (0.9)(\Delta C_{l,max})\left(\frac{S_{flapped}}{S_w}\right)\cos\left(\gamma_{HL}\frac{\pi}{180°}\right)$$

A Comparison of Methods and Results

The parameters determined via Corke's method, Raymer's method, and the Phase I methodology are compared in Table 17 below:

Table 17: Comparison of Methods and Results

Configuration	Method	$C_{L,max}$	$C_{L,TO}$	TO Ground Distance
C-130H (Baseline)	Corke	2.69	1.87	3488
C-130H (Baseline)	Raymer	2.63	1.82	3576
C-130H (Baseline)	Deshpande	2.62	1.82	3508
MedWing	Corke	2.92	2.03	2243
MedWing	Raymer	3.02	2.14	2127
MedWing	Deshpande	3.46 – 5.18 (*Ideal*)	2.4 – 3.6 (*Ideal*)	<1500 (*Ideal*)

Thus, it can be seen that all three methods show very good agreement in estimating C-130 baseline performance. This lends great confidence in the Phase I Methodology, since both Corke and Raymer have verified the results. However, there is some disagreement when it comes to the specific aerodynamic numbers for the MedWing C-130. A possible explanation for this may lie in the accounting of flap deflection angle. Recalling the discussion on Corke's method, it was decided that the flap deflection angle (δ_f) be set at 40 degrees. Recalling also Raymer's method, flap deflection angle was never used as an input at all (meaning that some standard historical value might be assumed therein). However, during what are called "max effort takeoffs," C-130 aircraft deflect their flaps to almost 90 degrees, in order to leave the ground in the shortest distance possible. (10) This would no doubt drastically increase the effective camber of the wing, leading to larger takeoff lift coefficients. Furthermore, it is also possible that the baseline C-130H data published (13) is for a more standard flap setting, rather than the max effort setting. This would explain why Raymer and Corke agree with the Phase I method regarding the baseline C-130 but not the MedWing configuration.

In the event that the Corke/Raymer results are in fact closer to the truth for the MedWing, then the resulting performance is still acceptable: A takeoff ground run of 2200 ft is still very promising in light of MedWing's "anyone, anywhere" mission, since it still affords access to over 99 % of all African runways (to be discussed shortly), not to mention countless locations without any runways at all.

However, there is only one way to find out what the truth actually is: Testing.

High-Lift Technique 3: Computational Fluid Dynamics (CFD)

The best way to ascertain the performance of a particular piece of hardware is through testing. However, in light of the present work, this requires either the procurement or the construction of an appropriate scale model (of either the wing or the full C-130), which is beyond the scope of this thesis (but not the next). As a substitute, computational fluid dynamics (CFD) studies are underway, in order to verify the performance of the *actual* MedWing modifications in a simulated environment. This study is still in its preliminary stages and will be explored in greater depth after the completion of this thesis. An example simulation of the clean wing at takeoff conditions is shown in Figure 36 below:

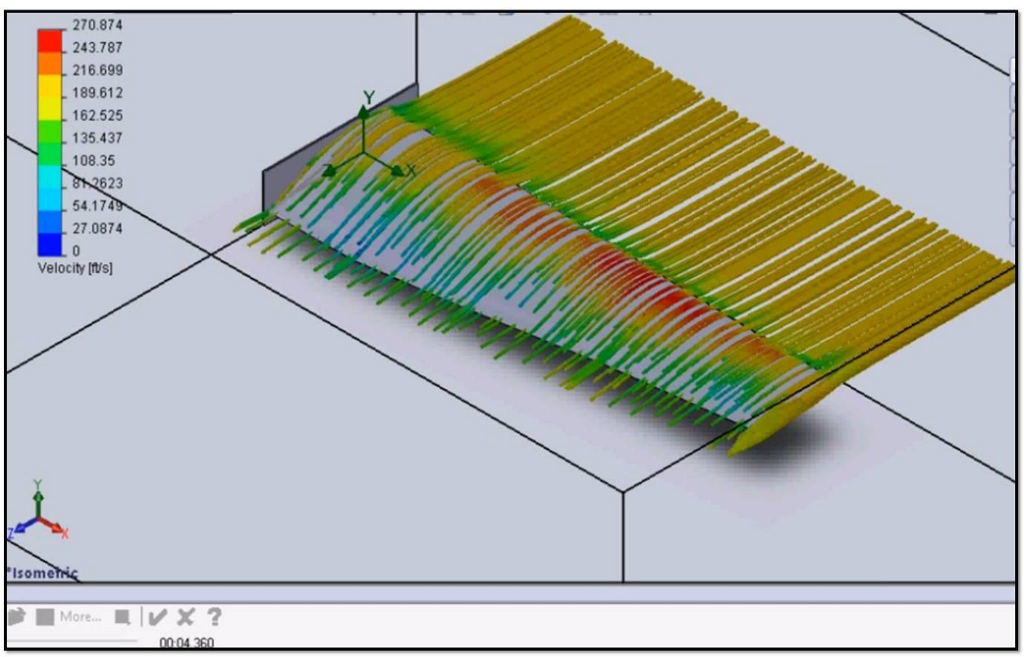


Figure 36: Example of CFD

This particular example was tested using SOLIDWORKS FloSimulation, which is a CFD package intrinsic to the SOLIDWORKS 3D modeling environment. Furthermore, the wing geometry itself was exported via DesignFOIL as mentioned above. This guarantees that the airfoils are sized, shaped, and located in the correct manner for geometric accuracy. Again, as mentioned above, CFD testing will be explored in greater depth after this thesis is complete.

MedWing Internal Configuration

Overview

In the introductory chapter, it was alluded to that the hospital systems would be modular such that the aircraft and hospital can be decoupled for greater mission flexibility. Now, it is time to unveil this arrangement:

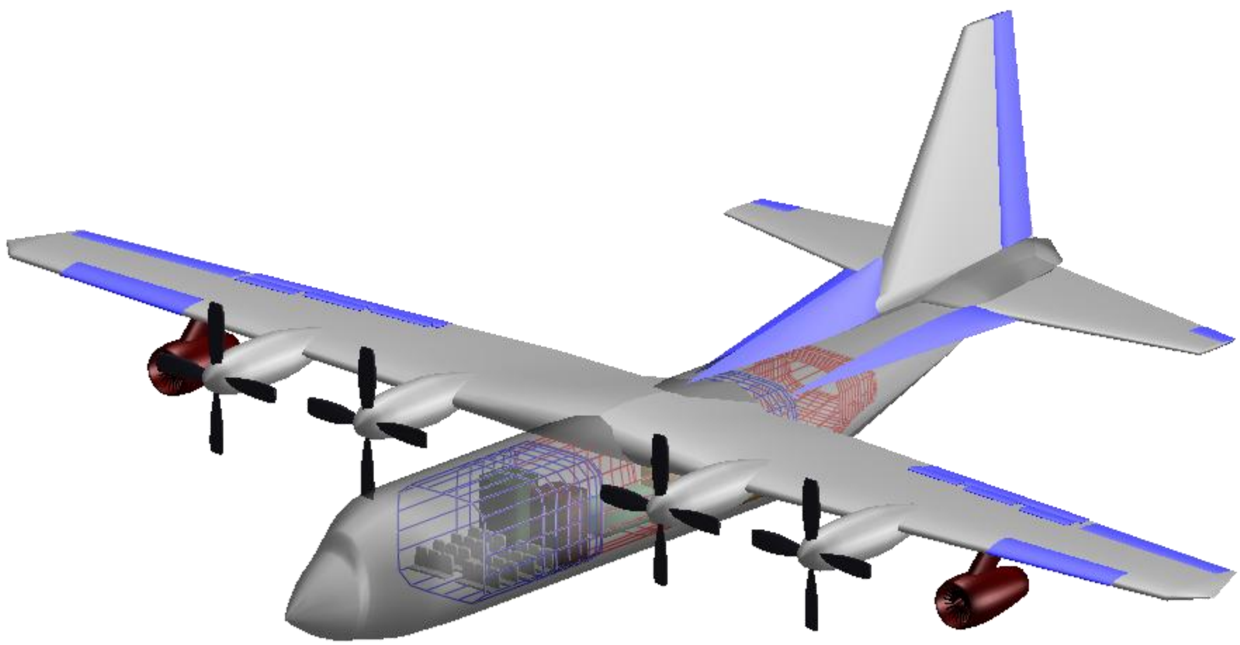


Figure 37: The MedWing Flying Hospital

As Figure 37 above shows, the hospital itself is containerized in order to take advantage of the inherent cargo-carrying capabilities of the C-130, which regularly transports palletized loads that are loaded and unloaded via a loading ramp with a rail system. (13) This allows for cargo containers to be rolled on and off in a very efficient manner. Similarly, the components of the Mobile Hospital will be designed such that the pieces can be transported in a similar manner. The modules are described in Figure 38 below:

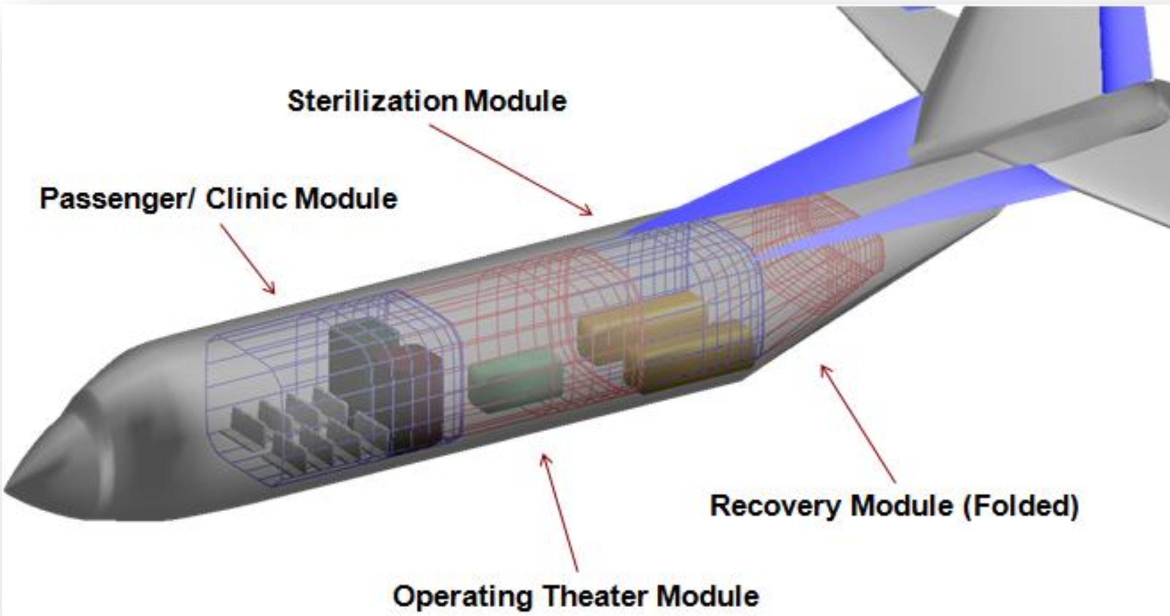


Figure 38: Hospital Modules

Each module is now discussed in greater depth below:

- **Passenger/Clinic Module**:
  - ➢ In flight, this compartment serves as the cabin, accommodating 25 doctors and/or other mission-critical personnel, with enough room for a small galley and lavatory. This module will be located directly behind the flight deck for easy access and communication between the command crew and passengers.

- On the ground, the module will serve as a functional clinic, so that basic treatment and care, such as vaccinations, blood sampling, pre-screening and checkup, and other small procedures, can ensue in a closed, semi-protected environment.
- In emergencies, it may be possible to recline some of the passenger seats to flat positions, in order to serve as extra beds for patients needing special attention and possibly intensive care.
- Additionally, this module can serve as a classroom, such that surgeries taking place in the operating theater (or elsewhere during a particular mission), can be televised via closed-circuit camera and monitor systems, in order to spread knowledge both to medical students and practitioners traveling with MedWing, as well as doctors from the location being serviced. This can help to ensure the spread of knowledge and also help lead to healthcare sustainability.
- Furthermore, if additional clinical and/or waiting area is desired, the wings can be used for shade (from the brutal sunlight expected during many of the missions), with the added possibility of drapes that can be hung from the wings in order to further shield patients while they are waiting or being checked, as well as offer them some level of privacy.

- **Operating Theater Module**:
  - This is the heart of the MedWing Flying Hospital: The operating theater (OT) is where surgeries and other intensive, complicated medical procedures will take

place (on the ground). The operating theater is an absolute must for humanitarian missions, whether they be disaster-relief operations (where surgical care is imperative but often unavailable), or health crisis alleviation efforts (where even a small procedure, such as a simple cataract surgery, can make a big difference in someone's life – just ask ORBIS).

- Since the operating theater is the heaviest component, it will be located near the vehicle's center of gravity so as to prevent unnecessary instabilities to the aircraft during flight.
- All of the equipment contained inside of the OT Module will be stowed in-flight to make room for medical supplies, as well as other equipment and cargo (including tents and other makeshift structures). The medical systems contingent to the OT Module's operation will be deployed after arrival to the mission location.

- **Substerile Module**:
  - In this module, doctors can prepare themselves before and after surgery, which involves sanitization of hands, equipment, and so on. This helps to ensure that all medical conduct is upheld to the highest standards of cleanliness and safety.
  - As with the OT Module, equipment and supplies will be stowed in-flight to utilize space efficiently and to maximize cargo-carrying capabilities.

- **Recovery Module**:
  - Patients requiring special attention and care after surgical and other procedures may be housed temporarily in the recovery area (which currently holds around 3 beds).
  - The module is folded in-flight and all of the components are stored to maximize space utilization. The folded module is stored just on top of the ramp and conforms to the shape of the volume enclosed by the undeployed ramp and fuselage.
  - The module will be unfolded upon landing and can be supported by the ramp (if modified appropriately) or through a deployable "wedge" underneath the module (this would help in avoiding modifications to the ramp). This implies that the module must be made of a flexible material for foldability but also a strong material for durability and protection of its inhabitants. One possibility is shown in Figure 39 below.
  - Additional recovery area may be obtained when the module is unfolded in order to accommodate more beds.

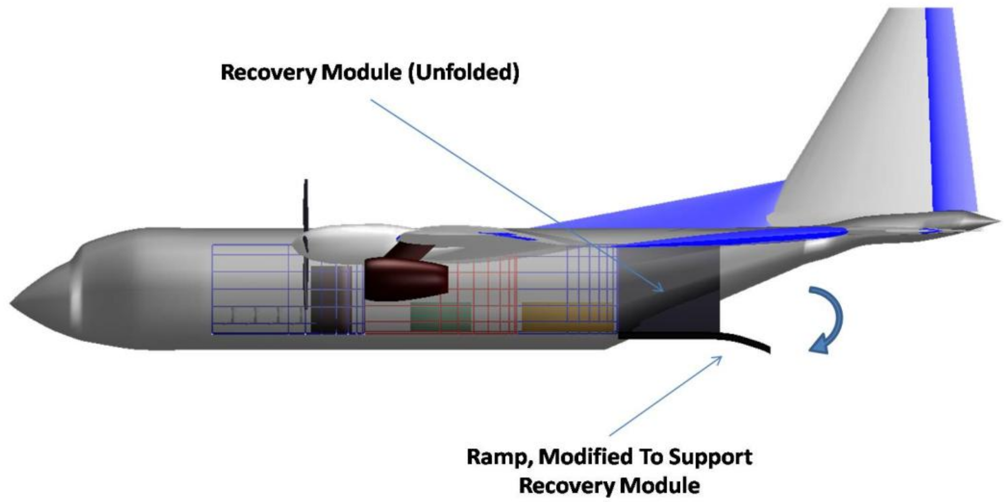


Figure 39: Recovery Module, Deployed Configuration

(NOTE: Alternatively, a wedge support may be used underneath the module to avoid modifications to the ramp).

Mission Flexibility

As stated in the introductory material, the hospital is special in that it takes advantage of the C-130's cargo-carrying features. Because of these features, MedWing has the unique opportunity to separate its hospital from its airplane by offloading the Mobile Hospital containers (as shown in Figure 40 below), in order to maximize the efficiency of both facets of this hybrid concept, lending the following benefits during a given humanitarian mission:

1) The *same aircraft* can now play a variety of roles, such as, say, rescuing fifty to one hundred people that are stranded somewhere, transporting critical care patients to other locations, ferrying supplies, equipment, and people between the mission location(s) and other sites, and a host of other functions. The

modularization of the hospital allows for a quick reconfiguration of the MedWing aircraft in order to serve in any of these roles.

2) In parallel with the aerial mission, the ground mission can ensue, with medical personnel and other team members treating those in need, using the now-deployed Mobile Hospital. This requires that the hospital be able to power itself independently when on the ground, in order to achieve the longest running time possible. It also means that the hospital must carry enough medicine, water, oxygen, and other portable power supplies (batteries and/or generators) to last for the duration of the mission. These challenges can be tackled in the following ways (to be explored further after as part of upcoming work):

   a) **Solar Power –** Many of the locations that MedWing wishes to serve receive great amounts of sunlight. While the wings, the cargo bay, and the containers can serve to provide shade to the patients and the mission team, some of the exposed surfaces can be temporarily or permanently covered with portable solar panels or solar rolls (rollable sheets of solar panels). This could help to offset some of the power requirements of the hospital by taking advantage of a readily available and abundant natural resource in a localized manner.

   b) **Wind Power –** Portable wind power can be explored as well in order to make use of all available resources during a given mission.

c) **Auxiliary Power Unit** – These are essentially small engines powered by a fuel source, often used in aircraft and ground vehicles to produce electrical power. They may be an option during missions (but are more of a last resort in order to avoid burning more fuel than necessary).

3) A drive towards sustainability has been hinted at throughout this thesis: In the present context, what does this mean? It is the hope of the creators of MedWing that some containers can actually be left behind with some of the communities being serviced – in this sense, the people there would have their own start-up clinic, and perhaps the beginning of a better, localized healthcare system. In light of this, volunteer doctors would be able to collaborate with and/or train the local doctors as necessary and give them the resources that *they* need (i.e. a medical facility) so that they can better care for their people when MedWing and other organizations move on to the next mission. This requires that the containers be made safe, effective, affordable, and eco-friendly, such that leaving certain containers and equipment behind is viable for both the local community and the servicing organization. This requires innovative design on the part of the MedWing founders. Said design challenges will be explored soon as the MedWing Project moves forward.

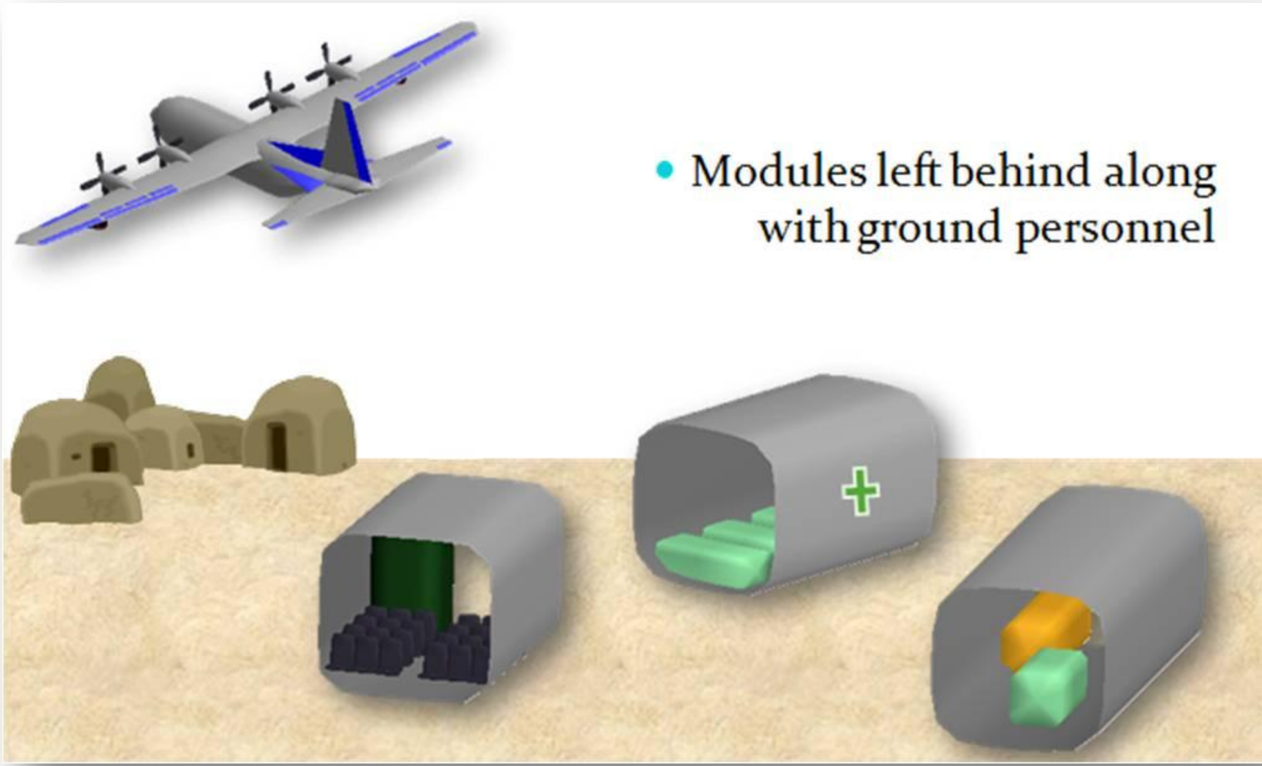


Figure 40: Sowing the Seeds of Change…

Impact Study:
An Assessment of What MedWing Can Do

It is now time to evaluate the potential impact that MedWing could have on the humanitarian world. The goal of this study is to make a preliminary assessment of MedWing's ability to access larger populations than ever before. While it would be difficult to map out every possible landing site via terrain evaluation (whether the site is a runway or an open field), it may be simpler to first chart which of the existing airstrips MedWing can access in order to reach more people. Taking Africa as a case study once more, the data on all African runways is summarized in Table 18 below:

Table 18: A Study of African Runways **(28)**

Statistics	#	%
Total Airports	1909	N/A
Total Paved Airports	649	34.0%
Total IFR Ready Airports	316	16.6%
Total Airports >=10,000ft	93	4.9%
Total Airports >=8,000ft	218	11.4%
Total Airports >=4,500ft	754	39.5%
Total Airports >=3,500ft	1246	65.3%
Total Airports >=2,000ft	1899	99.5%
Total Airports >=1,500ft	1908	99.9%
Total Paved >=8,000ft	206	10.8%

From the above, it can be seen that the total number of paved runways amount to only about 10% of those available across the entire continent. These same runways are probably located in or near urban communities, who tend to already have some level of healthcare in place. However, recalling Project MedWing's high-level objectives, it was decided previously that a 4,500-ft maximum takeoff distance would be required for any MedWing aircraft. This translates to 739 airstrips, or almost 40 %, that could be accessed by MedWing using a suitable aircraft, such as the Conceptual Design variant investigated by Mr. Hernandez in MedWing's parallel design effort. Furthermore, for an unmodified C-130 or similarly-capable aircraft, access would be granted to 1246 airstrips, or 65 %. Lastly, the MedWing C-130 proposed in this thesis, complete with the package of modifications investigated herein, would give MedWing access to 99 % of all African runways. *This is significant.*

Conclusions

The objective from the outset of this thesis has been to identify, investigate, and bring closer to implementation a performance modification-based Flying Hospital solution to the challenges facing our world. The engineering analysis and other studies performed herein show that through aerodynamic upgrades and propulsive add-ons, a C-130 aircraft can be modified to become a realistically implementable, cost-effective, viable flying hospital and humanitarian platform. The various analysis methods used throughout this work have indicated that the MedWing C-130 will be capable of 1500 – 2200 ft takeoffs and 1000 ft landings using rough, unprepared terrain, granting it access to around 99 % of African runways, as well as numerous locations with and without runways around the world. Furthermore, the conceptualization of a Modular Mobile Hospital, utilizing containerization and the C-130's inherent cargo-carrying abilities, has shown that aircraft-hospital independence is possible during a given mission, enabling each to be utilized as optimally as possible. Moreover, the opportunity for communal healthcare sustainability is on the horizon in light of this project, as knowledge, personnel, and some equipment, including some of the containers of the Mobile Hospital, can potentially be left behind in order to help create start-up clinics with better-equipped and better-prepared local doctors to serve the communities in need. All together, this is how MedWing plans to change the world …

Moving Forward …

Though the thesis may be over, Project MedWing has just begun. As stated previously, the founders of MedWing fully intend to implement their concept in reality – that too as soon as possible. This requires that important steps be taken next, not only to get MedWing the *airplane* off the ground, but also MedWing the *organization*. Keeping this in view, the author envisions the following steps:

- **Detailed Computational Analysis**: As highlighted in the Phase II chapter above, testing of the modifications is crucial to this endeavor. Preliminary fluid and structural tests will be run in a simulated environment before physical testing in order to hone in on the expected performance ranges in a fast, low-cost manner. This should hopefully reduce the overall cost and time spent in physical testing. Moreover, the impact of the new/additional systems on the aircraft's structural behavior will also be investigated in addition to aerodynamic behavior. In particular this will help to judge the effect of the modifications on the center wing box (CWB), which essentially supports the entire load acting on the aircraft, making it a critical component. Ensuring that this component does not ever fail during the lifetime operating cycle of the MedWing C-130 is absolutely imperative to the mission. Luckily, it is believed that the slower landing speeds afforded by the STOL system will help in reducing the impact energy of landing, thereby reducing the chance of structural failure.

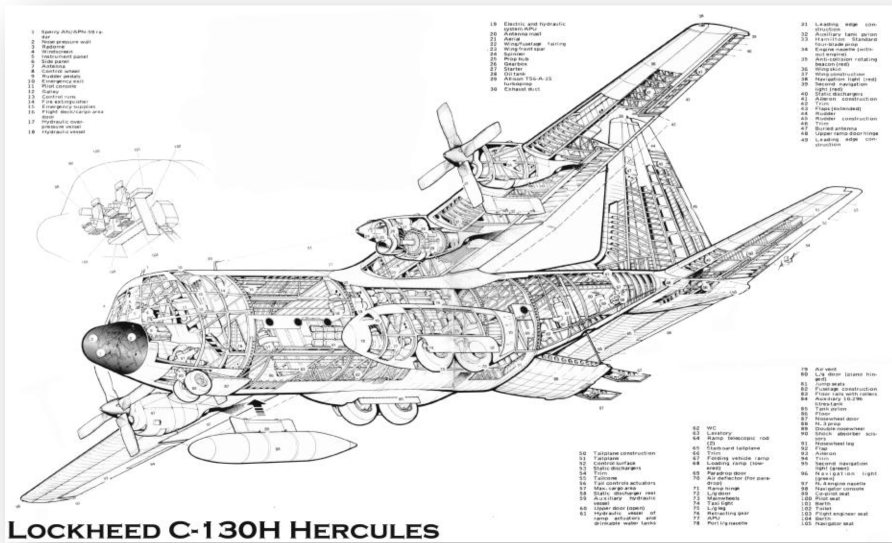


Figure 41: C-130 Structural Layout

- **Physical Testing**: Computers can only reveal so much about the physical performance of a particular piece of engineering hardware. Thus, during every project, there comes a time for testing. That phase is very close for Project MedWing. Since MedWing does not have access to a *real* C-130 at this time, it must utilize the next best thing: A scaled model. Thus, in light of this pursuit, several small scale models will be modified/ constructed in order to perform wind tunnel testing as well as *actual flight testing*, in which a Radio-Controlled (RC) flying testbed will be crafted and flown remotely in order to measure the dynamic performance of the modified aircraft. This will be done in such a manner that the small-scale performance can be matched to the large-scale performance of an actual C-130.

Figure 42: Example of a Scaled Flyable Model

- **Financial and Implementation Plan:** It our hope as the founders of MedWing that investor support may come soon. However, this requires that a solid financial and implementation plan be drafted before any sponsors can be seriously approached. Thus, we wish to create this plan within one year's time in order to begin approaching potential benefactors. The plan will outline the details of our operation as well as the finances involved, and it will also highlight when performance modifications and the like will come into play. One of the earlier steps in making MedWing a reality will of course be the attainment of an aircraft. As the saying goes, "You have to buy the house before you can tear it down," and thus, MedWing will have to obtain its aircraft early on and define what its specific, initial mission will be, before any internal and/or external modifications are made. Then, modifications can be brought into play as appropriate.

The author would like to close by asking again his original question: What does it take to change the world? Perhaps changing the world means being a part of it, not just through newspapers and websites, but through *real* connections. Whether it is a Flying Hospital or something as simple as spending a small part of our day helping someone, we always make connections through acts of caring. And when we connect, we grow, and when we grow, we really do help to create a brighter future.

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